ASSESSMENT OF FEASIBILITY AND UTILITY OF ROTATIONAL CORONARY ANGIOGRAPHY IN ROUTINE PRACTICE

A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF DM – BRANCH II CARDIOLOGY EXAMINATION OF THE TAMIL NADU DR. M.G.R. MEDICAL UNIVERSITY, CHENNAI TO BE HELD IN JULY/AUGUST 2009

CERTIFICATE

This is to certify that the thesis titled **"Assessment of feasibility and utility of rotational coronary angiography in routine practice"** is the bonafide work of the candidate **Dr. S. Jesu Krupa** in partial fulfilment of DM – Branch II (Cardiology) Examination of the Tamil Nadu Dr. M.G.R. Medical University, Chennai to be held in July/August 2009.

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Dr. S. Jesu Krupa

CONTENTS

ABSTRACT

ASSESSMENT OF FEASIBILITY AND UTILITY OF ROTATIONAL CORONARY ANGIOGRAPHY IN ROUTINE PRACTICE

Background: Coronary angiography is probably the most common invasive diagnostic procedure done these days and the workload of operators and staff in the catheterization laboratory is increasing rapidly. The overall number of projections is limited by time, safety and cost considerations and the usual compromise is to obtain a limited number of projections for each coronary artery. Rotational coronary angiography was designed to overcome some of these problems. There have been a few studies worldwide on this new technology and to the best of our knowledge, none from India. Hence, the present study was undertaken to test the feasibility of performing rotational angiography in a routine practice, in a busy cardiac catheterization laboratory setting.

Methods: Rotational angiography was performed on patients admitted for coronary angiography, including those with renal dysfunction and/or left ventricular dysfunction. Amount of contrast used, radiation dose, fluoroscopy time, pre and post-angiography glomerular filtration rate (GFR) (ml/min/1.73m^2) were studied to assess feasibility and safety of the procedure. Subgroup analysis on patients with compromised renal function and poor left ventricular ejection fraction (LVEF) prior to the procedure was done. The results were analyzed using appropriate statistical methods.

Results: The mean total contrast volume used for rotational coronary angiography in this study was 22.44 ± 5.16 ml (n = 64). This was significantly less ($p < 0.05$) as compared with the mean total contrast volume used for standard coronary angiography obtained from unpublished data in Christian Medical College, Vellore which was 38.16 ± 7.7 ml (n = 25). The mean Dose Area Product (DAP) in this study was 20.64 ± 7.18 Gycm^2. This was compared with data for standard angiography obtained from previously published data from Christian Medical College, Vellore which was 55.86 ± 5.75 Gycm^2. The difference between the two was statistically significant ($p < 0.0001$). There was a positive correlation of body mass index and fluoroscopy time with DAP. There was a reduction of fluoroscopy time with case numbers and hence a definite learning curve was demonstrated. In patients with LVEF < 50% and/or GFR < 60ml/min/1.73m^2, there was no significant worsening of GFR after rotational angiography. None of the patients developed contrast induced nephropathy. Rotational angiography provides just as good image quality and anatomic information as a standard coronary angiography. This was assessed by the primary operator and a consultant cardiologist, who independently reviewed the images.

Conclusion: Rotational coronary angiography offers a significant reduction in contrast volume and radiation dose when compared to standard coronary angiography while providing good image quality and anatomic information. It appears to have a definite role in patients at risk for developing contrast induced nephropathy

INTRODUCTION

Cardiovascular disease (CVD) was the leading cause of death globally in 2005, responsible for 17.5 million deaths, more than 80% of which occurred in low and middle-income countries (LMIC) [1].

By 2030, the number of cardiovascular deaths is projected to increase to 23 million, with about 85% occurring in these countries[2]. Already, CVD is the leading cause of death in China[3] and India[4], the world's 2 most populous countries. The CVD burden suffered by many LMIC now exceeds that suffered by many high income countries. CVD has a huge economic impact on individuals, households, and countries. The effects are particularly marked in LMIC, where CVD more frequently affects those of working age, and for this reason contributes disproportionately to lost potential years of he deaths occur before the age of 70 years, compared with just one-quarter in high-income countries[5]. Similarly, in India, CVD mortality in the working age population (30 to 59 years) is twice that in the U.S.[6].

Recent estimates of foregone gross domestic product (GDP) associated with CVD and diabetes for 23 LMIC highlight how such illnesses can significantly impair economic growth[7]. It was estimated that the aggregate loss in GDP across these countries in 2006 as a consequence of these diseases was $6.8 billion, with China, India, and Russia each incurring annual losses of over $1 billion. In a recent study in rural Andhra Pradesh, India, CVD was found to be the leading cause of death; however, less than one-sixth of those with a previous

cardiovascular event (mostly myocardial infarction) were receiving antiplatelet therapy[8].

India is experiencing an alarming increase in heart disease. The World Health Organization (WHO) estimates that 60 percent of the world's cardiac patients will be Indian by 2010. This rise in CVD may be due to metabolic differences in response to Western lifestyle of higher fat diets and lower levels of activity. Diabetes is a major health issue; India has 31.6 million diabetics, more than any other country. Indians have exaggerated insulin sensitivity in response to the Western life-style pattern. Furthermore, the proportion of calories derived from fat, much of which comes from dairy products, is significantly higher in India than in other parts of the developing world[9].

At Christian Medical College (CMC), Vellore, admissions due to CHD in a non-government hospital steadily increased from 4% in 1960 to 33% in 1989[10]. Proportional to the increase in incidence in coronary artery disease and hospital admissions for the same, there has also been a marked increase in the number of patients undergoing coronary diagnostic and interventional procedures. In 1995, there were approximately 600 angiographies and 250 angioplasties whereas in 2008, there were 2100 angiographies and 1300 angioplasties.

Coronary angiography is the most ubiquitous invasive diagnostic procedure in the industrialized world, the frequency of patient exposure to multiple coronary angiograms is common, and the workload of operators and staff in the catheterization laboratory is increasing rapidly.

Coronary angiography actually consists of a limited number of predetermined projections, individually adjusted by the operator according to the presumed geometry and orientation of the stenoses. The choice of the views is thus in part arbitrary and partly follows a trial and error process that should be applied to each lesion to get optimal visualization. However, because the overall number of projections is limited by time, safety and cost, the usual compromise is to obtain four to seven projections for the left and two to four for the right coronary artery. The resulting gap between adjacent projections, and thus the potential deviation from the optimal angle of observation, will range from 30° to >90° when only two projections are used. This gap can lead to serious underestimation of the severity of the stenosis and of its length.

Rotational coronary angiography was designed to overcome these problems and provide a panoramic representation of the coronary tree as a rotating image conveying complete three-dimensional information, giving a better insight into the coronary tree and permitting a more accurate reconstruction of complex anatomies. There have been a few studies worldwide on this new technology and to the best of our knowledge, none from India.

Hence, the present study was undertaken to test the feasibility of performing rotational angiography in a routine practice, in a busy cardiac catheterization laboratory setting.

AIMS AND OBJECTIVES

Aim:

The aim of this study is to assess the feasibility of rotational coronary angiography in routine practice.

Objectives:

1. To perform rotational angiography instead of standard angiography in consecutive patients undergoing coronary angiography.
2. To assess the radiation dose and contrast volume used in rotational coronary angiography as compared to standard coronary angiography.
3. To determine the occurrence of contrast induced nephropathy in patients undergoing rotational coronary angiography.
4. To assess renal function before and after rotational angiography, in patients with pre-existing renal and/or LV dysfunction.
5. To assess the image quality and adequacy of anatomic information provided by rotational angiography for further management.

REVIEW OF LITERATURE

History of coronary angiography:

Among the first to describe and work on coronary arteries was Leonardo da Vinci (1452–1519). The closed circulation of blood was described one hundred years later by William Harvey (1628) (Exercitatio anatomica de motu cordis et sanguinis in animalibus).

The cardiologist, William Heberden (1710–1801) was the first to exactly recognize and describe angina in his publication “Some account of a disorder in the breast”; it appeared in the College of Physicians on July 20, 1768. The American cardiologist James B. Herrick (1861–1954) made an important contribution to the analysis of coronary sclerosis in the paper “Clinical features of certain obstructions of the coronary arteries”. He concluded in 1912 that “a slow, gradual narrowing of coronary vessels is a possible cause, permitting the heart to adapt to the new conditions, and that a severe obstruction of a vessel must not necessarily lead to death”. He brought this theory to Europe in 1918, propagating it widely; he also created the term “heart attack”. Herrick described in 1918 the electrocardiographic changes after ligation of the coronary vessels.

The first coronary heart catheterization was performed in 1929 by Werner Forssmann in his famous “self-experiment”. Forssmann worked with a catheter for bladders, Charrière 4, which he introduced approx. 65 cm deep into the right auricle, applying the jugular vein. His achievement was scarcely noticed so that

Forssmann abandoned the idea of catheterization. The lung specialist André Cournand, however, was fascinated by the procedure: together with the cardiologic pediatrician Dickinson Richards, he successfully repeated in 1941 the trial of Forssmann. The catheter was pushed into the right auricle; by 1942, they were able to push it further and place it into the right ventricle.

The rapid development of angiography in the early 1950s led to the ardent wish for a depiction of coronary arteries by means of intervention. Contrast material was injected into the aorta, flowing from there into the coronary vessels, resulting, however, quite often in an insufficient filling of contrast material[11].

Mason Sones (1918–1985), a cardiologic pediatrician, solved the problem: in performing an angiogram following the well-known technique on a 26-year-old man, the catheter slipped inadvertently from the aorta into the right coronary artery. By this, all contrast material was injected and went into the right coronary artery instead of the aorta. Monitoring of catheterization was not known at that time, yet the mishap of the wrongly performed injection remained without consequences, no damage was observed. Mason Sones immediately grasped the important consequence of the situation: he replaced supra-aortic injections by selective coronary angiography, that is, by injecting smaller amounts of contrast medium into the relevant coronary vessel. This was a breakthrough, and the technique became a routine procedure in the Cleveland Clinic in 1959.

Lastly, no history of the development of coronary arteriography would be complete without acknowledging the important contributions of Drs. Judkins[12] and Amplatz[13]. Both of these radiologists used the Seldinger percutaneous

technique[14] to gain access to the femoral artery. Independently, they designed preformed catheters, the conformity of which sought out the ostia of either the left or right coronary artery as well as facilitating access to the left ventricle. It was these preformed catheters that made successful engagement of the coronary ostia a much easier process that required far less training than the Sones' technique, which required a brachial cut down, requiring much more time to become skillful. Undoubtedly, this facilitated the widespread dispersion of angiography as a diagnostic technique throughout the cardiology and radiology communities.

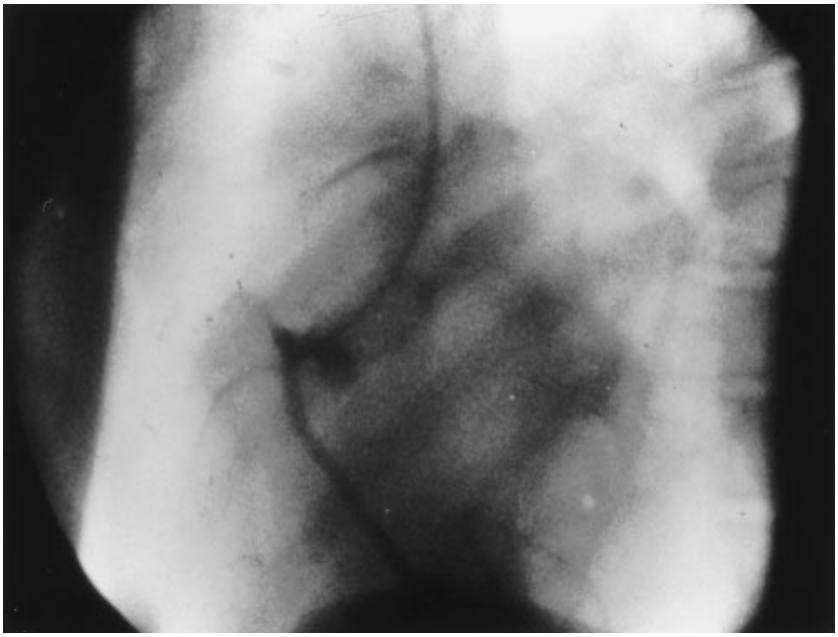


Figure 1. Cine frame from the first selective coronary arteriogram taken by F. Mason Sones, MD, on October 30, 1958.

Indications for coronary angiography:

The various current indications for coronary angiography are summarized comprehensively in the AHA/ACC guidelines on coronary angiography[15]. The most frequent indication is the further evaluation of patients in whom the diagnosis of coronary atherosclerosis is almost certain and in whom anatomic correction by means of coronary bypass surgery or percutaneous coronary intervention is contemplated. Angiographic evaluation of coronary anatomy in such patients provides the crucial information needed to select the most appropriate treatment strategy - catheter intervention, bypass surgery, or medical therapy. Included in this category are patients with stable angina pectoris refractory to medical therapy. Even asymptomatic patients with noninvasive evidence of myocardial ischemia also benefit from revascularization and are thus candidates for coronary angiography[16]. In patients with unstable angina, more than two thirds of such patients will come to angiography within 6 weeks of presentation anyway owing to ongoing clinical symptoms or a positive exercise test[17, 18]. Patients with acute myocardial infarction routinely undergo immediate coronary angiography followed by same-procedure primary angioplasty[19].

A second group of indications for coronary angiography consists of patients in whom the presence or absence of coronary artery disease is unclear[15]. This includes patients with troublesome chest pain syndromes but ambiguous noninvasive test results, patients with unexplained heart failure or ventricular arrhythmias, survivors of out-of-hospital cardiac arrest[20], patients with suspected

or proven variant angina[21], and patients with risk factors for coronary artery disease who are being evaluated for major abdominal, thoracic, or vascular surgery[22]. This category also includes patients scheduled for correction of congenital or valvular pathology. Patients with congenital defects such as tetralogy of Fallot frequently have anomalies of coronary distribution that may lead to surgical complications if unrecognized[23], whereas patients older than age 45 years with valvular disease may have advanced coronary atherosclerosis without clinical symptoms. Although younger patients with valvular disease are commonly operated on without prior coronary angiograms, given the extraordinary low risk of diagnostic catheterization and the potential benefit of knowing the coronary anatomy, most surgical center personnel believe it is best to perform a preoperative diagnostic catheterization to identify (and then correct) significant coronary lesions, to provide the best and safest outcome during concurrent valve replacement[24].

Finally, coronary angiography is frequently performed when a patient develops recurrent angina after coronary intervention or after bypass surgery (to detect vein graft failure, which might require catheter intervention or reoperation). Routine follow-up angiography 6 months after catheter intervention is not indicated clinically, but may play an important role in the research evaluation of new technologies or drug therapies targeted at reducing restenosis[25].

Standard coronary angiography:

Coronary angiography actually consists of a limited number of predetermined projections, individually adjusted by the operator according to the presumed geometry and orientation of the stenoses. The choice of the views is thus in part arbitrary and partly follows a trial and error process that should be applied to each lesion to get optimal visualization. However, because the overall number of projections is limited by time, safety and cost, the usual compromise is to obtain four to seven projections for the left and two to four for the right coronary artery. The resulting gap between adjacent projections, and thus the potential deviation from the optimal angle of observation, will range from 30° to >90° when only two projections are used. This gap can lead to serious underestimation of the severity of the stenosis and of its length. Besides being incomplete, this information entails considerable redundancy because each projection includes several cardiac cycles, yielding a series of highly intercorrelated images. From all these limitations, it appears clear that the conventional approach is not optimal.

Rotational coronary angiography:

To overcome these limitations, Tomassini et al in 1998, described a new approach that uses a dynamic rather than a fixed perspective, obtained by transverse 180° rotation of the C arm of a conventional angiographic unit,

accomplished manually in 4 seconds during standard selective coronary opacification and filming[26].

To evaluate the influence of foreshortening on the apparent length and severity of the stenosis they used a simple model of a concentric stenosis, based on a narrow tube (the stenosis) interposed between two larger tubes of equal radius (the normal segments) aligned on the same axis. This model and the corresponding silhouette from three different perspectives are depicted in Figure 2. The correct perspective, which avoids foreshortening, is perpendicular to the axis of the tubes. Deviation from this perspective leads to progressive underestimation of the length and, above a certain threshold, of the severity of the stenosis.

Figure 2. Model of concentric stenosis and the corresponding silhouette at different angles of observation.

The position of the patient was initially adjusted under fluoroscopy so that the heart lay approximately isocentric to the C arm. The image intensifier was 25° cranially or caudally tilted, then positioned 90° right lateral, close to the thoracic wall, and the C arm was manually rotated from the right to the left side during coronary injection and filming (Figure 3).

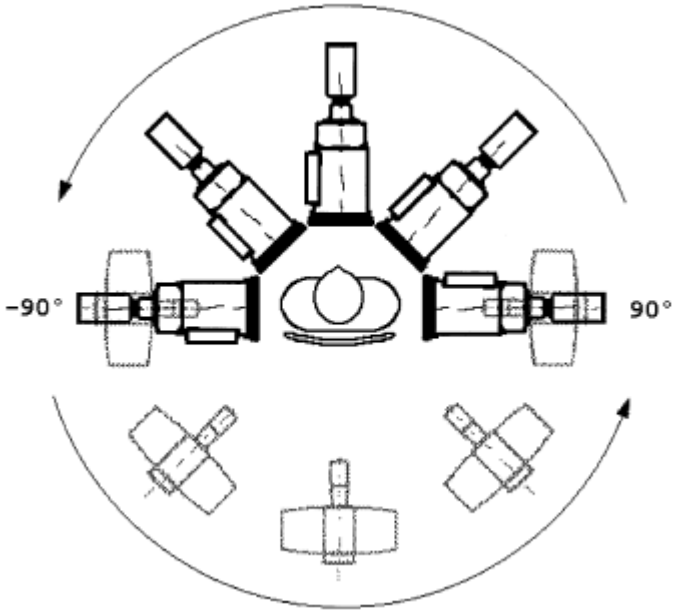


Figure 3. Schematic representation of a rotational scan. The image intensifier is positioned 90° right lateral with a fixed 25° cranial or caudal tilt. The C arm is then manually rotated to a -90° left lateral position in ~ 4 seconds.

The potential for serious underestimation of the severity of stenosis was highlighted in this study as shown in Figure 4.

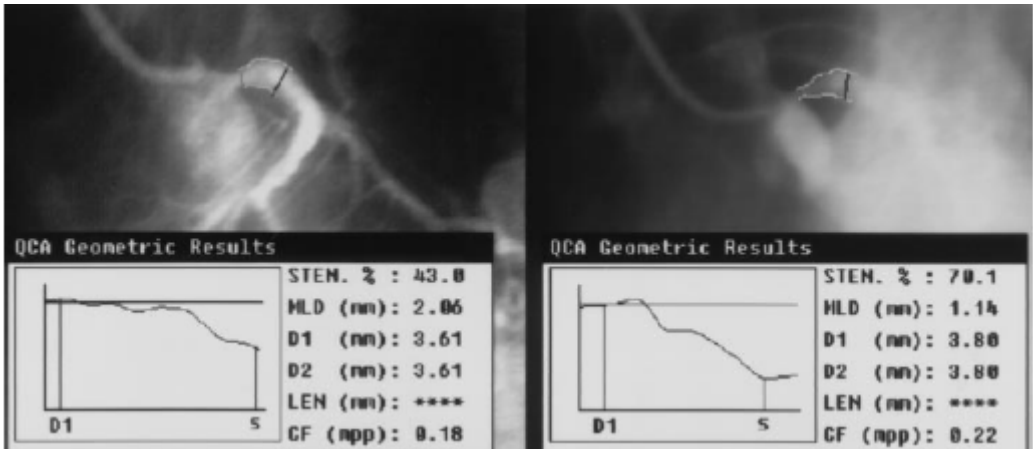


Figure 4. Severe ostial stenosis of the left main coronary artery seriously underestimated by the standard projections. Maximal stenosis (STEN) severity was 43% in a standard cranial 45° LAO projection **(left)** versus 70% in a rotational image approximately corresponding to a 20° cranial LAO projection **(right)**.

A complete diagnostic run for both coronary arteries, including two 25° cranial and two 25° caudal scans was accomplished with a total cine time of 16 sec and 45 ml of contrast medium, about half of that required by conventional angiography.

Hence, of 129 consecutive patients studied by both the conventional and the rotational technique with quantitative measurements of the severity of the stenoses, the final diagnosis was identical in 65. In no case was a stenosis detected only by the conventional approach. However, in 31 patients the new technique permitted identification of 34 critical stenoses (79 ± 8% [mean ± SD]) either underestimated (61 ± 3% n = 24, $p < 0.001$) or undetected (21 ± 22%, n = 10, $p < 0.001$) in the standard projections. In a further 28 cases, 33 subcritical lesions (60 ± 5%) were visualized in the rotational images but were insignificant

(24 ± 22% $p < 0.001$) in the standard projections. In five additional patients, distinct laminar plaques were clearly visualized only by the panoramic approach.

Rotational angiography offers the following advantages according to this study:

1. Visualization of every lesion from all perspectives in the transverse plane in a single run, yielding maximal information with no redundancy.

2. Panoramic representation of the coronary tree as a rotating image conveying complete three-dimensional information. This gives a better insight into the coronary tree and collateral circulation and permits a more accurate reconstruction of complex anatomies.

3. Standardized, operator-independent approach. The panoramic technique does not rely on presumptive hypotheses on actual anatomy and does not involve an empirical choice of the most suitable projection to visualize a specific lesion. All information is obtained by two rotational scans with fixed 25° cranial and caudal angulation. Hence, this approach is standardized and basically operator independent, which is expected to improve reproducibility.

4. Improved diagnostic accuracy. In this study, comparative analysis of the results was carried out by using the conventional classification of stenoses based on percent diameter reduction. The use of all transaxial projections allowed identification of a substantial number of critical stenoses which were either underestimated or undetected by the conventional technique. Also, several subcritical but significant (>50% and <70%) lesions were only detected by the new technique.

5. Use of less contrast medium and shorter cine runs. A complete rotational study comprises four scans, approximately 45 ml of contrast and 16 sec of cine, approximately half required by conventional coronary angiography.

Kuon et al in 2002, demonstrated using a conventional image intensifier system that, compared with the standard techniques of coronary angiography, the method of rotational spin in invasive cardiology requires significantly less contrast medium: the 2 runs required for rotational coronary angiography necessitated 25 ± 4 ml consumption versus 64 ± 9 ml for complete documentation in standard mode[27]. Overall radiation dose for the spin mode was slightly but not significantly higher than the overall standard mode. In this study, it was established that rotational spin enabled adequate image quality, comparable to standard mode. The proximal and mid segments as well as the periphery of the right coronary artery (RCA) achieved the best evaluation scores for cardiac spin, whereas the mid and proximal segments of the circumflex artery and the left anterior descending artery were judged slightly worse than for standard mode. The method of rotational cardiac spin was able to exactly document multiple left coronary artery (LCA) lesions and to reliably disclose lesions at crucial regions, such as the RCA ostium and bifurcations in circumflex and obtuse marginal arteries.

In 2004, Maddux et al published a randomized study of the safety and clinical utility of rotational angiography versus standard angiography in the diagnosis of coronary artery disease[28]. This was the first randomized study to compare

prospectively, the safety and clinical utility of rotational coronary angiography to standard coronary angiography. Fifty-six patients undergoing coronary angiography were enrolled in this study. Twenty-eight patients were randomized to standard angiography and 28 patients were randomized to rotational angiography. A ceiling-mounted Philips Integris Allura 12” monoplane system was used. The standard angiography protocol consisted of four images of LCA using the traditional four gantry angles (LAO cranial, LAO caudal, RAO cranial, and RAO caudal views) and two different projections of the RCA (LAO, RAO, or AP cranial views). The specific gantry angles chosen and the magnification settings were per the operator’s discretion. The rotational angiography protocol consisted of three rolls or automated acquisition trajectories. Two 120° rotations (60° RAO to 60° LAO) were performed using both a 25° cranial and 25° caudal tilt during image acquisition of the LCA. A single 120° rotation (60° RAO to 60° LAO) with a 25° cranial orientation was performed during image acquisition of the RCA. Each 120° acquisition was completed in 4 sec. The primary endpoint of the study was patient safety (total contrast and radiation dose). The secondary endpoints of the study were operator safety (radiation exposure); time to complete a suitable angiographic study, and the clinical utility of rotational angiography using the number of additional image acquisitions needed above the protocol as an index of the adequacy or lack of adequacy of the rotational acquisition technique. Contrast utilization in the rotational angiography group was lower than in the standard angiography group (35.6 ± 12.6 vs. 52.8 ± 10.7 ml, respectively; $p < 0.0001$). This represents a 33% reduction in contrast use in

patients randomized to the rotational angiography group. Total radiation exposure was also markedly reduced in the rotational angiography group (37.2 ± 13.2 vs. 53.9 ± 23.4 $Gycm^2$, respectively; $p < 0.002$). This represents a 31% reduction in total radiation exposure in patients randomized to the rotational angiography group. Total whole-body radiation exposure or effective dose equivalent (EDE) to the primary operator was substantially lower in the rotational angiography group as compared to standard angiography (144 vs. 170 mrem, respectively). Patients randomized to the rotational angiography had a 41% reduction in the total number of image acquisitions needed to complete a diagnostic study (3.96 ± 1.17 vs. 6.75 ± 0.80 acquisitions, respectively; $p < 0.0001$). The rotational protocol was completed in all patients with no crossover to standard angiography. One major advantage of rotational angiography over standard angiography is that it provided a large amount of information regarding the coronary tree with the use of less contrast and radiation. Using the rotational image acquisition protocol in this study, up to 360 projections from different angles of the coronary tree were obtained during a single angiographic study. During the standard angiographic protocol in this study, only six different projections of the coronary tree were obtained at the cost of higher contrast medium and radiation exposure to the patient. Furthermore, fluoroscopy radiation dose needed to isocenter the camera for image acquisition in the rotational angiography protocol was 66% lower than that required to center the camera for image acquisition during the standard angiography protocol. In accordance with the “as low as reasonably achievable” (ALARA) principle of the National Council

on Radiation Protection and Measurements (NCRP), the rotational angiography technique provides reduced patient radiation risk without the loss of the benefit of a complete angiographic study[29]. There was no significant difference in the need for additional image acquisitions between the two groups. The need for additional angiographic images in the standard group may reflect the frequency of vessel overlap and foreshortening, which is not fully appreciated during standard angiography. The need for a second view of a coronary segment was more evenly distributed between the two groups; however, this response was seen more frequently in the rotational group. One explanation for this may be that more cranial or caudal orientation was needed in some patients during the set rotational protocol. In the rotational group, attending physicians felt that they needed to magnify on an area of interest to evaluate a coronary segment of interest. However, with flat detector imaging systems becoming widely available, the need for magnification does not require additional image acquisitions since digital magnification alone is sufficient. The advantages and disadvantages of rotational versus standard coronary angiography as summarized in this study are as follows:

Advantages

1. Reduces radiation exposure to the patient and all personnel.
2. Reduces contrast dose to the patient.

3. Provides additional perspectives of coronary artery tree, especially important for ostial, bifurcation, and very eccentric lesions.
4. Produces a 3D visual effect helping operator's assessment of branching patterns.
5. Reduces the reliance on the operator's skills to find optimal views.
6. Allows standardization of images acquisition protocols.
7. Images are internally calibrated to allow quantitative coronary angiography (QCA) without external calibration objects.

Disadvantages

1. No table panning during image acquisition is possible so that larger field of view may be needed to keep entire coronary tree in all images.
2. Cannot be performed on older angiographic systems without rotational capabilities.
3. Requires operator and staff to learn proper isocentering technique.
4. Operator must learn to review angiographic runs with a constantly changing perspective.

In 2005, Akhtar et al published a randomized study of the safety and clinical utility of rotational vs. standard coronary angiography using a flat-panel detector[30]. Their rotational system included three advances over prior studies: the use of a flat-panel imaging system; the height of the flat-panel detector was

lowered maximally to reduce the source-to-image distance; and the first 0.5 sec of each rotational angiogram included acquisition with a fixed gantry position to allow ascertainment of coronary calcification prior to injection of contrast as well as coronary velocity with the initiation of contrast injection. They hypothesized that the use of rotational angiography would reduce contrast utilization and X-ray exposure while achieving the same level of diagnostic accuracy. All angiographic procedures were performed from the femoral arterial approach using a ceiling-mounted flat-panel detector monoplane system with a rotational angiographic software package (Allura Xper FD 10, Philips Medical Systems, Bothell, WA). Hand injection of up to 10 ml of contrast was used for selective coronary angiography. Two 100º rotations (RAO 50º to LAO 50º) with either a 25º cranial or 30º caudal tilt were performed for LCA acquisition. A single 100º rotation (RAO 50º to LAO 50º) with 25º cranial tilt was performed for RCA acquisition. Contrast utilization in the rotational angiography group was 40% lower as compared to the standard angiography group (24 ± 5 vs. 40 ± 10 ml, respectively; $P < 0.0001$). Radiation exposure and fluoroscopy time was not significantly different between the rotational or standard angiography groups. There was no significant difference in the need for additional image acquisitions beyond the protocol acquisitions in the rotational and standard angiography groups. To assess the impact of the learning curve for rotational angiography, subgroup analysis was performed comparing early (n = 13) vs. late (n = 12) studies within each study arm. In the rotational angiography arm, early studies tended to utilize more time for coronary acquisition. Early studies also used more fluoroscopy time

compared to late studies. In addition, all cases requiring additional image acquisitions in the rotational arm occurred during the early phase.

In 2007, Garcia et al published an initial clinical experience of selective coronary angiography using one prolonged injection and a 180º rotational trajectory[31]. This study demonstrated the feasibility and safety of longer coronary injections of 7.2 sec. There were no significant HR changes, clinically insignificant pressure changes, and no adverse reactions. A newer application of rotational angiography which is undergoing research is 3 D reconstruction of coronary models from angiogram images as shown in Figure 5.

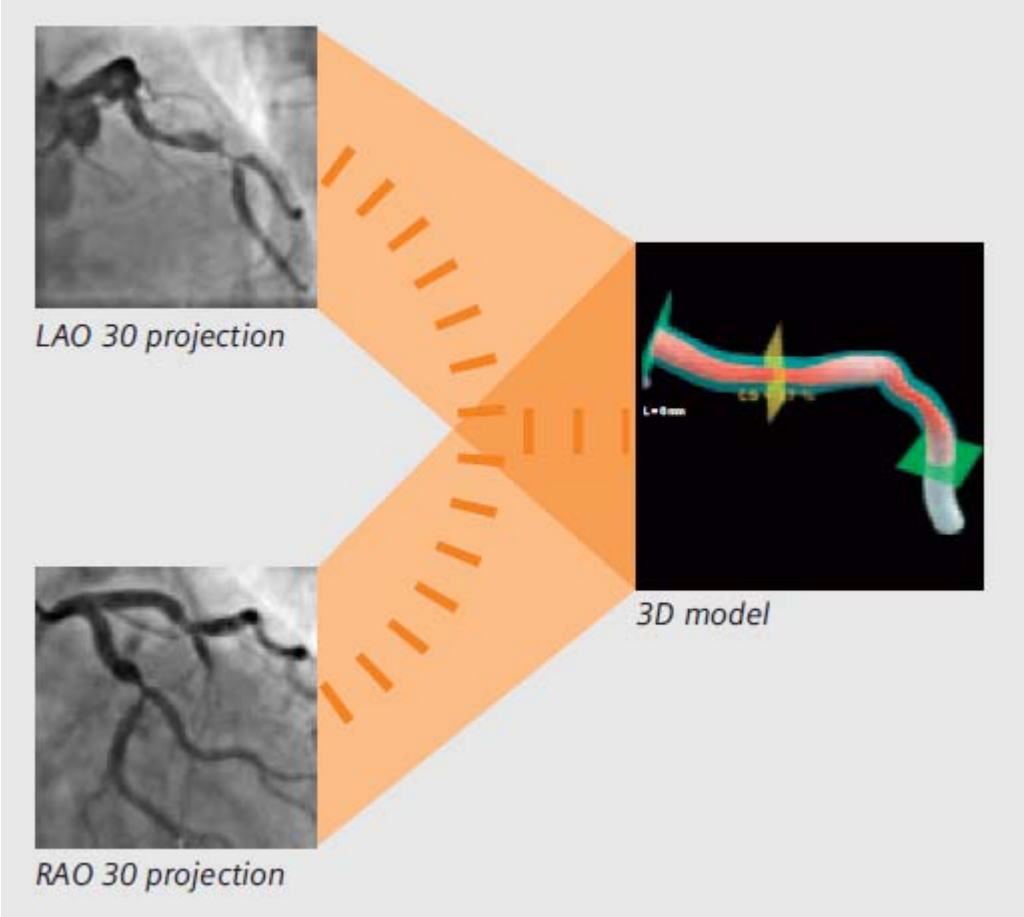


Figure 5. 3 D model obtained from rotational angiogram images

In 2009, Garcia et al published a study[70] that compared the image content of rotational angiography with standard angiography. This study showed that rotational angiography provides a similar if not superior image analysis capability when compared to standard angiography. Quantitative and qualitative lesion assessment is a pivotal part of coronary angiography. Rotational angiography has the power to detect a similar or higher amount of lesions when directly compared to standard angiography. Moreover it is comparable to standard angiography in evaluating lesion severity and ACC lesion type. The screening adequacy of rotational angiography has also been evaluated. The study shows that when comparing both imaging modalities side by side and evaluating all vessel segments and calcification, there is no significant difference between them.

Some differences however are worth mentioning. Standard angiography seems to be superior in the evaluation of TIMI flow and collaterals. Because the rotational run usually begins right before the acquisition begins it becomes difficult to evaluate TIMI flow. However, newer rotational acquisition protocols include an initial delay in the run (0.5 sec) so that TIMI flow can be evaluated. With the inclusion of this feature there would be no difference between rotational angiography and standard angiography in the evaluation of TIMI flow and probably on vessel collateralization. On the other hand rotational angiography seems to be superior to standard angiography in the visualization of several coronary artery segments (first diagonal, distal RCA, postero-lateral branches, and the posterior-descending artery). In addition it seems to deliver a better

survey of the different coronary ostiums although this was not rigorously evaluated. In this study, rotational angiography had a 40% reduction on contrast exposure and a 15% reduction in radiation exposure when compared to standard angiography.

Definitions:

Exposure is the radiation level at a point in space, commonly measured with an ionization chamber in units of air kerma (kinetic energy released in material; dose delivered to air).

Dose refers to the local concentration of energy absorbed by tissue from the x-ray beam when the exposure interacts with the individual atoms in the tissue.

Dose area product (DAP) is the product of the air dose at a certain distance from the x-ray tube and the cross sectional area of the x-ray beam at the same distance. The unit is the gray cm^2. DAP is actually independent of distance; as distance increases, air dose decreases and beam size increases in an exactly offsetting manner. Because most of the x-ray beam is absorbed by the patient, DAP is a conveniently measurable surrogate for effective dose. Most currently used interventional fluoroscopes include a DAP meter. DAP includes both fluoro and cine exposure and reflects the influence of tissue thickness on skin dose. But because the same DAP can be delivered as either a high dose to a small field size or as a low dose to a large field size, it cannot be used directly to predict the possibility of a skin injury (which would be significantly higher in the former case).

Flat-Panel X-Ray Detectors

The image intensifier/video camera combination is currently being displaced by integrated digital image receptors (flat-panel detectors). The imaging behavior of a flat-panel system differs from an image intensifier/digital video system in one important respect. As shown in Figure 6, when an image intensifier is zoomed, less and less of the patient is imaged by the tube's fixed-size output screen. Therefore each pixel in the zoomed image is smaller (relative to the patient) than for the unzoomed case; i.e., spatial resolution increases with zoom. In the flat-panel case, zooming simply uses fewer of the available pixels, so that the intrinsic spatial resolution does not increase with zoom. However, the digitally magnified image on the monitor may provide better detail coupling to the observer's eye, increasing the clinically effective resolution as a flat-panel system is zoomed[32]. Figure 7 shows a Philips Allura XP FD10 Flat-Panel Detector.

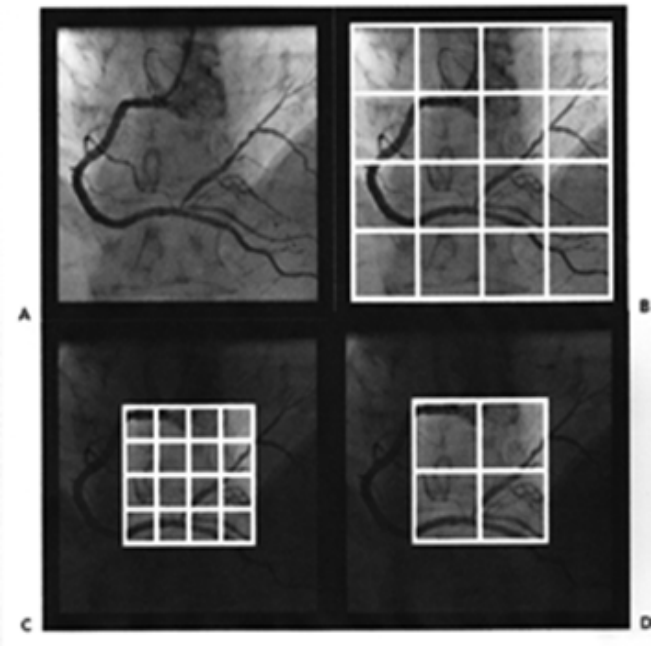


Figure 6. Zoom differences between image intensifiers and flat-panel detectors. The image before digitization (A); full-field digitization for both systems - typically a matrix size of 1,024 x 1,024 (B). When the image intensifier is zoomed (C), the same matrix covers a smaller field of view; this reduces the effective pixel size. When a first-generation flat-panel is zoomed (D), the pixel size remains the same; fewer pixels are used. Displays are usually electronically zoomed to fill the monitor. This does not increase physical resolution, but may improve the visibility of detail.

Figure 7. Philips Allura XP FD10 (Flat-Panel Detector)

Biologic effects of radiation:

Stochastic Effects

The word stochastic is defined as involving chance or probability. Stochastic effects are presumably induced by a single photon causing unrepaired injury to the DNA of a single viable cell. Depending on their type, damaged cells can proliferate to produce a malignancy in the irradiated individual or a genetic disorder in future generations. The severity of the resultant injury, caused by propagation of a single (unrepaired) damaged cell, is independent of the dose that started the process[33, 34]. Because manifestation of the injury requires cellular propagation, stochastic effects are typically seen years to decades after irradiation. Radiation-induced leukemia thus occurs between 2 and 25 years after irradiation, whereas solid radiogenic cancers have a latent period of 5 to 20 years.

Deterministic Effects

Deterministic effects occur when a significant number of existing cells are sufficiently damaged so as to cause observable injury. Immediate injury is either owing to massive cell killing or a prompt biochemical tissue response to radiation. Delayed injuries become manifest when injured cells die without being replaced. The threshold dose for a deterministic effect depends on the fraction of cells that need to be killed before tissue loses viability, whereas the time course is dependent on the nature of the tissue and its cellular kinetics.

As of 2005, new imaging systems for the catheterization laboratory are required to record not only fluoroscopy time but also DAP or Kerma Area Product (KAP) [35, 36]. DAP/KAP is a more accurate assessment of skin dose than fluoroscopy time by accounting for both cine acquisition and fluoroscopy; it is the standard for assessing post procedure skin injury[37]. These deterministic effects of radiation toxicity begin with early transient erythema at 2 Gy and progress to ischemic dermal necrosis at 18 Gy[36]. The stochastic effects reflecting cancer risk have no definable threshold.

Contrast induced nephropathy:

The reported incidence of contrast-induced acute kidney injury (AKI) varies widely across the literature, depending on the patient population and the baseline risk factors. The most commonly used definition in clinical trials is a rise in serum creatinine (SCr) of 0.5 mg/dl or a 25% increase from the baseline value, assessed at 48 hours after the procedure. It has been recognized for some time that the risk of death is increased in patients developing contrast-induced AKI[38-42].

In a large retrospective study of over 16,000 hospitalized patients undergoing procedures requiring iodinated contrast, patients with contrast-induced AKI had a 5.5-fold increased risk of death[43]. In contemporary studies, contrast-induced AKI requiring dialysis developed in almost 4% of patients with underlying renal impairment[44].

Chronic kidney disease (CKD) is identified by an estimated glomerular filtration rate (eGFR) < 60 ml/min/1.73 m^2. Almost every multivariate analysis has shown that CKD is an independent risk predictor for contrast-induced AKI[44-49]. Since SCr alone does not provide a reliable measure of renal function, the National Kidney Foundation Kidney Disease Outcome Quality Initiative recommends that clinicians should use an eGFR calculated from the SCr as an index of renal function rather than using SCr[50] in stable patients. The risk of contrast-induced AKI is increased in patients with an eGFR < 60 ml/min/1.73 m^2, and special precautions should be taken in these patients[51]. Other risk markers include diabetes mellitus (DM) [52, 53], volume depletion[54], nephrotoxic drugs, hemodynamic instability[55, 56], and other comorbidities. Anemia has also been reported as a predictor of contrast-induced AKI[57]. However, the concept is that in a patient with CKD, DM, and other comorbidities, predicted risks of contrast-induced AKI and emergency dialysis can approach ~ 50% and ~ 15%, respectively. Iodixanol has been shown to have the lowest risk for contrast-induced AKI in patients with CKD and DM[58, 59].

Volume of contrast - Numerous studies have shown that the volume of contrast medium is a risk factor for contrast induced AKI. The mean contrast volume is higher in patients with contrast-induced AKI, and most multivariate analyses have shown that contrast volume is an independent predictor of contrast-induced AKI[48, 52, 56, 60]. However, even small volumes (~ 30 ml) of contrast medium can have adverse effects on renal function in patients at particularly high risk[61]. As a

general rule, the volume of contrast received should not exceed twice the baseline level of eGFR in milliliters[62]. This means for patients with significant CKD, a diagnostic catheterization should plan to use ~ 30 ml of contrast, and if followed by PCI then ~ 100 ml should be a reasonable goal. Volume expansion and treatment of dehydration has a well-established role in prevention of contrast-induced AKI, although few studies address this theme directly. There are limited data on the most appropriate choice of intravenous fluid, but the evidence indicates that isotonic crystalloid (saline or bicarbonate solution) is probably more effective than half-normal saline[63]. Although popular, N-Acetyl Cysteine (NAC) has not been consistently shown to be effective. Importantly, only in those trials where NAC reduced SCr below baseline values because of decreased skeletal muscle production did renal injury rates appear to be reduced. Thus, NAC appears to falsely lower Cr and not fundamentally protect against AKI. However, NAC as an antioxidant has been shown to lower rates of AKI and mortality after primary PCI in 1 trial[64]. The recently published REMEDIAL (Renal Insufficiency Following Contrast Media Administration) trial suggested that the use of volume supplementation with sodium bicarbonate together with NAC was more effective than NAC alone in reducing the risk of AKI[65].

In adults the best equation for estimating glomerular filtration rate (GFR) from serum creatinine is the Modification of Diet in Renal Disease (MDRD) Study equation[66].

GFR (mL/min/1.73 m2) = 186 x $(Scr)^{-1.154}$ x $(Age)^{-0.203}$ x (0.742 if female) x (1.212 if African-American)

METHODOLOGY

The study was performed among consecutive patients undergoing coronary angiography at the Cardiology Department of Christian Medical College, Vellore; a tertiary care institute in South India. This study was approved by the Institutional Review Board (IRB).

Inclusion criteria:

Patients undergoing coronary angiography, including those with renal dysfunction and/or LV dysfunction.

Renal dysfunction is defined as GFR < 60ml/min/1.73m^2

LV dysfunction is defined as LVEF < 50%

Exclusion criteria:

- Known allergy to iodinated contrast
- Acute coronary syndrome
- Decompensated heart failure
- Prior coronary-artery bypass- graft (CABG)
- Pregnancy

Rotational coronary angiography:

Patient baseline demographics, including serum creatinine and LVEF were noted prior to the procedure.

All angiographic procedures were performed after written, informed consent, from the femoral arterial approach using a ceiling-mounted flat-panel detector

monoplane system with a rotational angiographic software package (Allura Xper FD 10, Philips Medical Systems). Coronary angiography was performed with a standard catheter set including Judkins Left and Judkins Right catheters. Controlled hand injections were used for selective coronary angiography. All procedures were performed by a single operator, who was a cardiology trainee.

Iohexol (Omnipaque) was the contrast used for most of the patients. Iodixanol (Visipaque) was used when the serum creatinine was > 1.3 mg/dl. Patients with serum creatinine > 1.3 mg/dl prior to the procedure received saline hydration and NAC. Patients assigned to rotational angiography had a total of three coronary acquisitions specified by the protocol. Prior to acquisition, the patient's heart was isocentered using fluoroscopy in the anteroposterior and left lateral positions. Once contrast injection was initiated, the cine pedal was pressed and high-speed rotation of the gantry was initiated in a predefined trajectory. Initiation of the rotation was started immediately after contrast was noted to fill the entire coronary. During spin acquisition, the gantry moved through an arc at a rate of 27.5°/sec. Two 110º rotations (RAO 55º to LAO 55º) with a 25º cranial and 25º caudal tilt were performed for LCA acquisition. A single 110º rotation (RAO 55º to LAO 55º) was performed for RCA acquisition. Each rotational acquisition was completed in 4 sec and 121 frames. All cine angiograms were recorded at 15 frames/sec. Additional coronary acquisitions were taken when required at the discretion of the operator and a consultant cardiologist.

Fuoroscopy time was recorded from the time of arterial sheath insertion till the completion of coronary angiography. Two other measures of radiation dose [dose

area product (DAP, $Gycm^2$) and air kerma (Gy)] for fluoroscopy and image acquisition were recorded from the Philips Allura Xper system.

Coronary contrast media utilization used to acquire the protocol and any additional coronary angiographic images was recorded.

The patient was hemodynamically monitored during the procedure and was watched for any adverse event including contrast allergy.

Assessment of images was done by the primary operator and a consultant cardiologist, which was in terms of image quality and adequacy of anatomic information provided for further management.

Serum creatinine was checked and recorded 48 hours after coronary angiogram.

Statistical analysis:

Data was presented using percentages and means with standard deviation. The comparison of contrast volume used and radiation dose in rotational angiography and standard angiography was assessed using students t test and confidence intervals for the same were constructed. Pre and post angiogram renal function was tested for statistical significance using the paired t test. Pearson's correlation coefficient was used to analyze the correlation between BMI and radiation dose and fluoroscopy time and radiation dose. Results were considered statistically significant at $p < 0.05$. The statistical analysis was performed using Microsoft Excel 2003 and SPSS for Windows (15.0).

RESULTS

A total of 64 patients were studied. Table 1 shows the demographic characteristics of the patients studied.

The mean age of the subjects was 55.42 ± 7.54 years; they were predominantly males (79.7%). There were 27 (42.2%) diabetics and 33 (51.6%) were hypertensive. The mean BMI was 23.76 ± 3.98 kg/m^2. The mean cardiothoracic ratio (CTR) was 50.73 ± 6.58 %. There were 2 patients (3.1%) who had end-stage renal disease and were on hemodialysis. The mean serum creatinine was 1.20 ± 0.91 mg/dl and the mean GFR was 75.01 ± 18.92 ml/min/1.73m^2. The mean LVEF was 50.38 ± 8.85 %. Twenty three patients (43.8%) had normal coronaries and 8 (12.5%), 9 (14.1%), 7 (10.9%), 8 (12.5%) had single, double and triple vessel coronary artery disease respectively. One patient (1.6%) had left main with double vessel disease and 3 patients (4.7%) had left main with triple vessel disease. Thirty one patients underwent renal angiography out of which 27 (87%) had normal renal arteries, 2 (6.4%) each had minor and significant renal artery disease respectively.

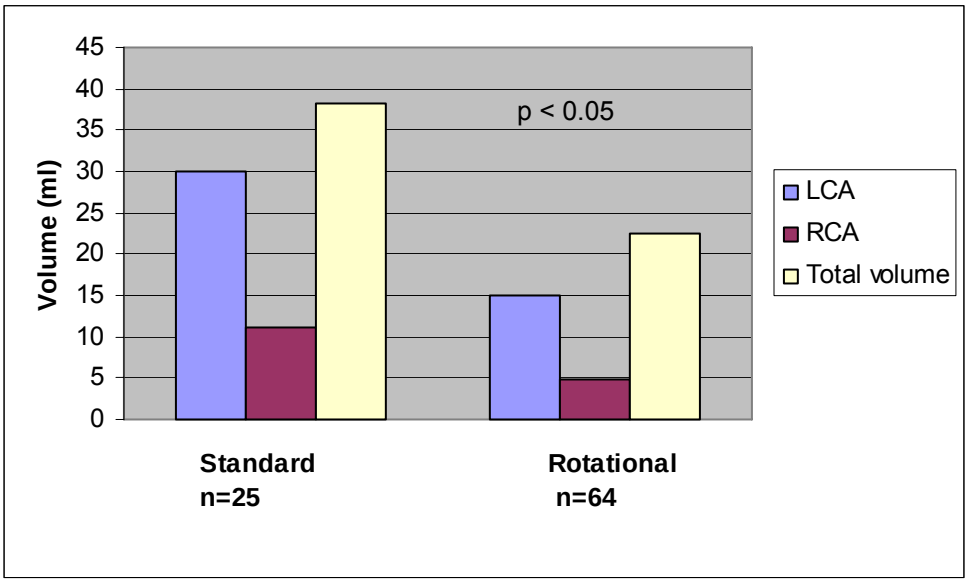
Table 1. Demographic characteristics (numbers in brackets indicate percentages)

Mean age (years) ± SD	55.42 ± 7.54
Male sex	51 (79.7)
Mean height (cms) ± SD	163.34 ± 7.60
Mean weight (kg) ± SD	62.83 ± 10.19
Mean BMI (kg/m^2) ± SD	23.76 ± 3.98
Mean CTR (%) ± SD	50.73 ± 6.58
Renal disease	2 (3.1)
Diabetes Mellitus	27 (42.2)
Hypertension	33 (51.6)
Smoking	21 (32.8)
Dyslipidemia	12 (18.8)
Previous ACS	19 (29.7)
Mean serum creatinine (mg/dl) ± SD	1.20 ± 0.91
Mean GFR (ml/min/1.73sq.m.) ± SD	75.01 ± 18.92
Mean LVEF (%) ± SD	50.38 ± 8.85
Coronary angiogram (n = 64) Normal Minor SVD DVD TVD LDVD LTVD	 28 (43.8) 8 (12.5) 9 (14.1) 7 (10.9) 8 (12.5) 1 (1.6) 3 (4.7)
Renal Angiogram (n = 31) Normal Minor RAS	 27 (87) 2 (6.4) 2 (6.4)

SD = Standard Deviation, BMI = Body Mass Index, CTR = Cardio Thoracic Ratio, ACS = Acute Coronary Syndrome, GFR = Glomerular Filtration Rate, SVD = Single Vessel Disease, DVD = Double Vessel Disease, TVD = Triple Vessel Disease, LDVD = Left main with Double Vessel Disease, LTVD = Left main with Triple Vessel Disease, RAS = Renal Artery Stenosis.

The mean total contrast volume used for rotational coronary angiography in this study was 22.44 ± 5.16 ml (n = 64). The mean contrast volume used for LCA and RCA was 15.03 ± 2.17 ml and 4.95 ± 0.82 ml respectively. This was compared with the mean total contrast volume used for standard coronary angiography obtained from unpublished data in Christian Medical College, Vellore which was 38.16 ± 7.7 ml (n = 25). The mean contrast volume used for LCA and RCA was 26.96 ± 5.7 ml and 11.2 ± 3.25 ml respectively.

Figure 1. Comparison of contrast volume used for standard versus rotational angiography



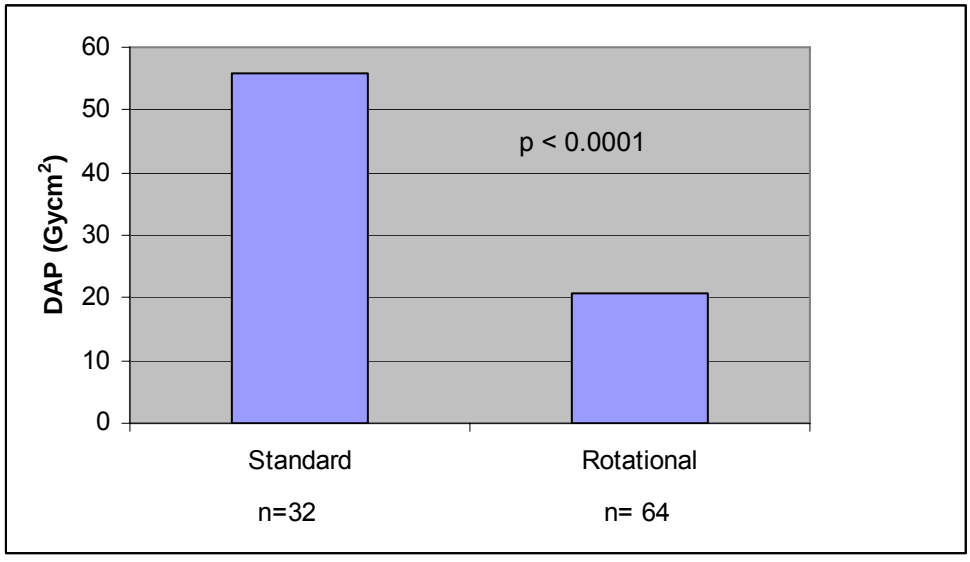
LCA = Left Coronary Artery, RCA = Right Coronary Artery

Table 2. Contrast Volume used for standard coronary angiography and rotational angiography

	Standard	Rotational	P value	95% CI	
				Lower	Upper
LCA (ml)	26.96 ± 5.7	15.03 ± 2.17	< 0.05	9.63	14.22
RCA (ml)	11.2 ± 3.25	4.95 ± 0.82	< 0.05	4.96	7.53
Total Volume (ml)	38.16 ± 7.7	22.44 ± 5.16	< 0.05	12.48	19.03

There was a statistically significant reduction in contrast volume used in rotational angiography as compared to standard angiography.

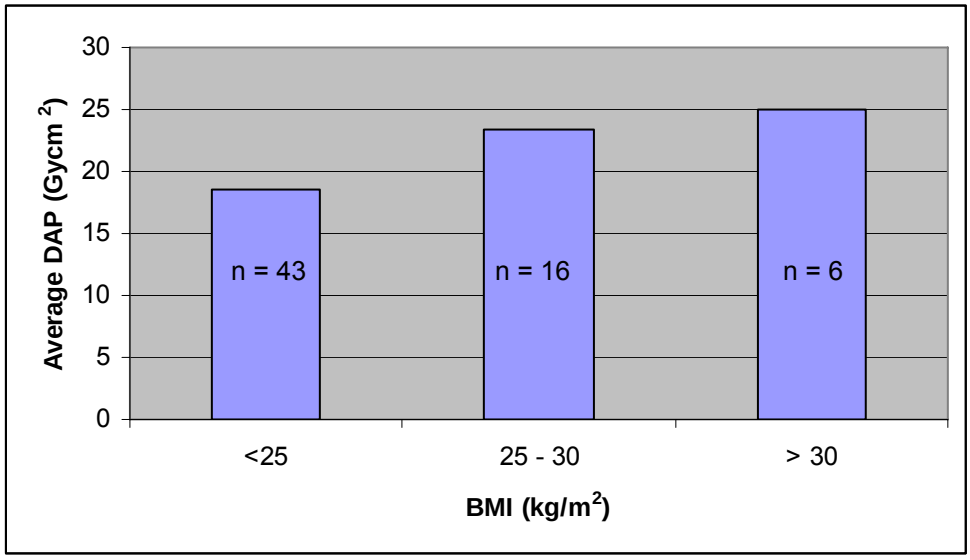
Figure 2. Comparison of radiation dose for standard versus rotational angiography



DAP = Dose Area Product, SD = Standard Deviation

The mean DAP in this study was 20.64 ± 7.18 $Gycm^2$. This was compared with data for standard angiography which was obtained from previously published data from Christian Medical College, Vellore[67]. The radiation dose for standard angiography was 55.86 ± 5.75 $Gycm^2$. The difference was statistically significant ($p < 0.0001$). The 95 % CI of this estimate was 32.36 – 38.07.

Figure 3. DAP Values According to BMI



DAP = Dose Area Product, BMI = Body Mass Index

The average DAP was 18.5 ± 5.49, 23.44 ± 7.66, 30.01 ± 9.29 $Gycm^2$ for patients with BMI < 25, 25-30 and > 30 kg/ m^2 respectively. Figure 3 shows graphically that there was a trend to higher DAP values for patients with a higher BMI. Figure 4 shows a positive correlation in the scatter plot where $r^2 = 0.34$. This correlation

was found to be significant ($p < 0.0001$) on analysis using Pearson's correlation coefficient.

Figure 4. Scatter plot showing the relation between DAP (Gycm^2) and BMI (kg/m^2)

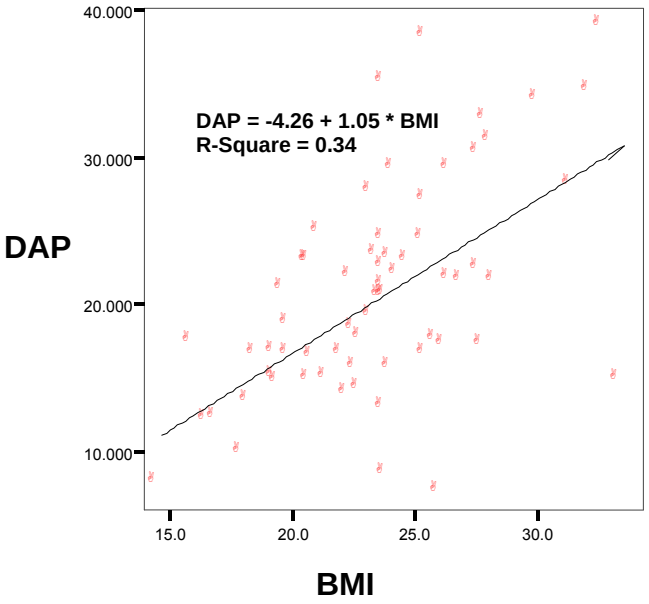


Table 3. Pearson's correlation coefficient statistics

Modality	Mean	Standard deviation	Pearson's correlation coefficient with DAP	Significance (2 tailed)
BMI (kg/m^2)	23.76	3.97	0.579	< 0.0001
Fluoroscopy time (min)	1.65	0.77	0.461	< 0.0001

Figure 5. Scatter plot showing the relation between DAP (Gycm^2) and Fluoroscopy time (min)

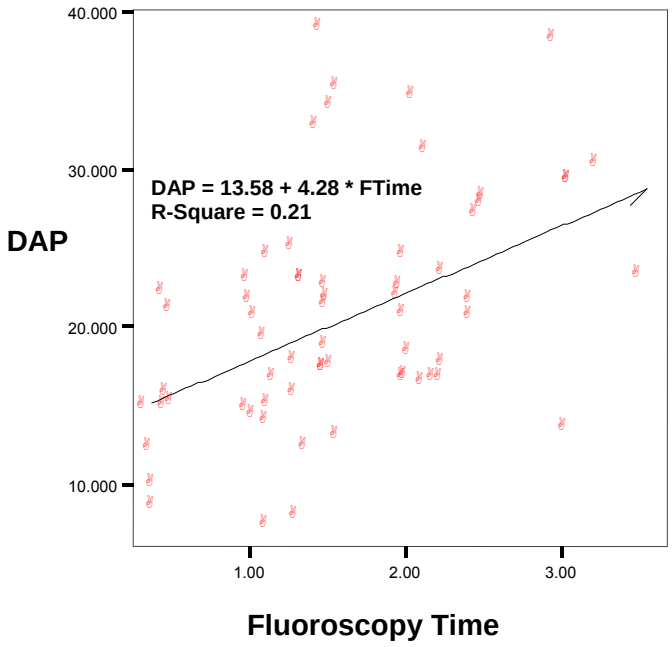
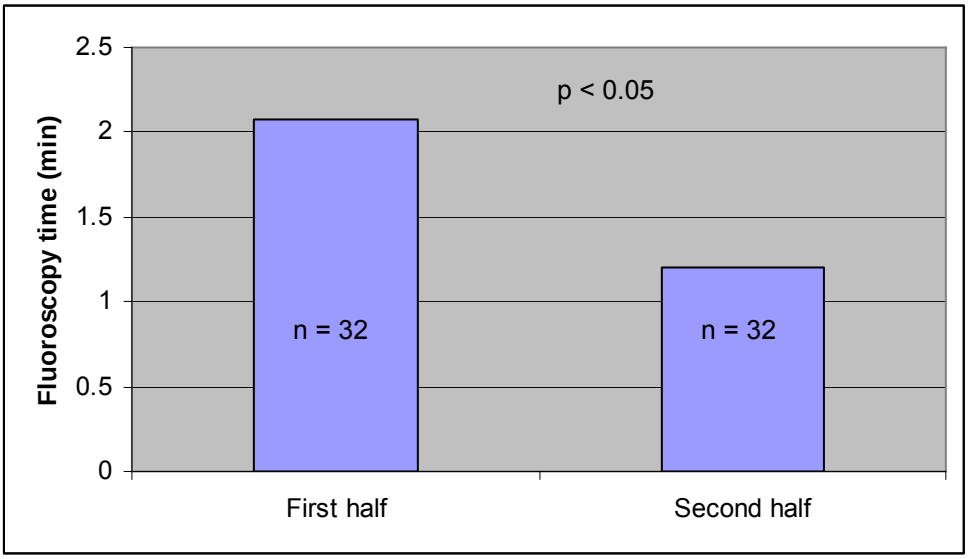


Figure 5 shows a positive correlation between DAP and fluoroscopy time in the scatter plot where $r^2 = 0.21$. However, DAP had a stronger correlation with BMI than fluoroscopy time.

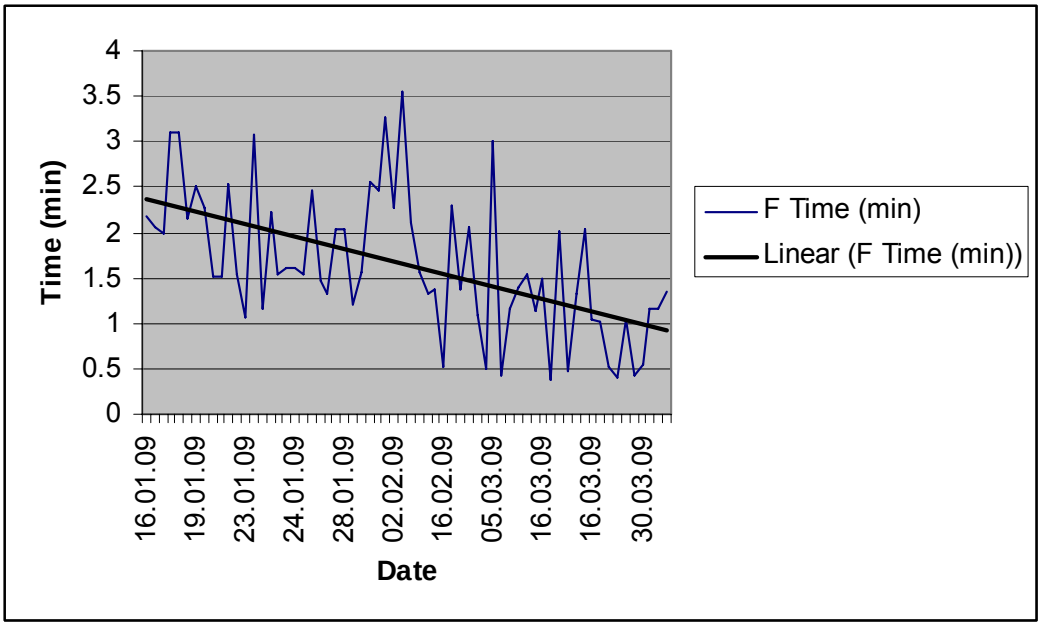
Figure 6. Comparison of fluoroscopy time in first and second halves of the study



Patients who underwent rotational angiography (n = 64) were divided into two groups. The first 32 patients were included in the 'first half' group and the remaining patients were included in the 'second half' group. The mean fluoroscopy time in the 'first half' group was 2.07 ± 0.65 min as compared to 1.22 ± 0.64 min in the 'second half' group. The difference in the mean fluoroscopy time of the two groups was statistically significant ($p < 0.05$).

Hence, there is a definite learning curve involved in rotational angiography. Figure 7 graphically depicts the gradual reduction in fluoroscopy time with case numbers.

Figure 7. Learning curve for rotational angiography



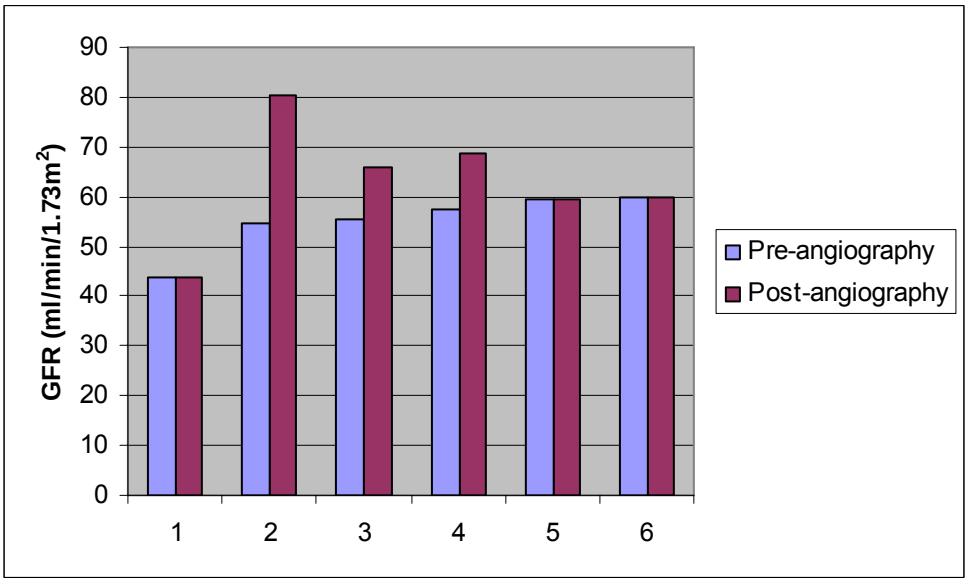
A sub group analysis was done on patients with compromised renal function and reduced LVEF prior to the procedure.

There were a total of 8 (12.5%) patients with pre-procedural GFR < 60 ml/min/1.73m^2. Two (3.1%) of these patients had end-stage renal disease and were on maintenance hemodialysis. Hence, no post-angiography serum creatinine was done for these patients. Table 3 shows the pre-angiography and post-angiography GFR. None of the 6 patients had worsening of GFR post angiography. Figure 8 shows graphically that there was no worsening of GFR after rotational angiography in patients with a baseline GFR of < 60 ml/min/1.73m^2. The difference in GFR, pre and post-angiography was not significant (p = 0.116).

Table 3. Comparison of pre-angiography and post-angiography GFR in patients with baseline GFR < 60 ml/min/1.73m^2

S.No	Pre-angiography	Post-angiography
1	9.17	NA
2	12.11	NA
3	43.83	43.83
4	54.58	80.47
5	55.32	66.09
6	57.49	68.68
7	59.65	59.65
8	59.71	59.71

Figure 8. Comparison of pre-angiography and post-angiography GFR in patients with baseline GFR < 60 ml/min/1.73m^2



Paired Samples Test

		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	Df	Sig. (2-tailed)
					Lower	Upper			
Pair 1	GFR1 - GFR2	-7.9750	10.29463	4.20277	-18.77855	2.82855	-1.89	5	.116

The other subgroup was that of patients with an LVEF < 50%. There were 22 patients with LV dysfunction. The mean LVEF was 39.27 ± 5.68 %. In these patients the pre-angiography and post-angiography GFR was compared. Table 4 shows a comparison of pre-angiography and post-angiography GFR in patients with baseline LVEF < 50%.

Table 4. Comparison of pre-angiography and post-angiography GFR in patients with baseline LVEF < 50%

S.No	Pre-angiography	Post-angiography
1	54.58	80.47
2	55.32	66.09
3	60.96	41.34
4	61.38	61.38
5	62.90	56.35
6	64.88	64.58
7	65.21	65.21
8	65.87	65.87
9	68.40	57.25
10	70.75	70.75
11	70.98	64.66
12	72.09	72.09
13	72.57	72.57
14	76.60	63.17
15	81.57	81.57
16	83.40	83.40
17	91.49	91.49
18	93.12	93.12
19	94.18	94.18
20	98.01	84.01
21	102.06	90.38
22	110.13	110.13

The difference in GFR, pre and post-angiography was not significant (p= 0.30).

Paired Samples Test

		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	Df	Sig. (2-tailed)
					Lower	Upper			
Pair 1	GFR 1 - GFR 2	2.09500	9.24437	1.97091	-2.00372	6.19372	1.063	21	.300

No patients in the study developed contrast induced nephropathy.

However, 9 (14 %) patients had a GFR < 60 ml/min/1.73m^2 post-angiography.

The mean age of this group of patients was 56 ± 6.0 years and 5 (55.6%) were males. Five (55.6%) of these patients were diabetics.

The pre-angiography and post-angiography GFR is tabulated in Table 5 and the paired t test showed the difference to be significant (p = 0.031).

Table 5. Comparison of pre-angiography and post-angiography GFR in patients with post-angiography GFR < 60 ml/min/1.73m^2

S.No	Pre-angiography	Post-angiography
1	60.96	41.34
2	43.83	43.83
3	66.33	55.52
4	62.90	56.35
5	68.40	57.25
6	57.25	57.25
7	59.65	59.65
8	59.71	59.71
9	65.60	59.85

Paired Samples Test

		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
					Lower	Upper			
Pair 1	GFR 1 - GFR 2	5.98667	6.88773	2.29591	.69229	11.28104	2.608	8	.031

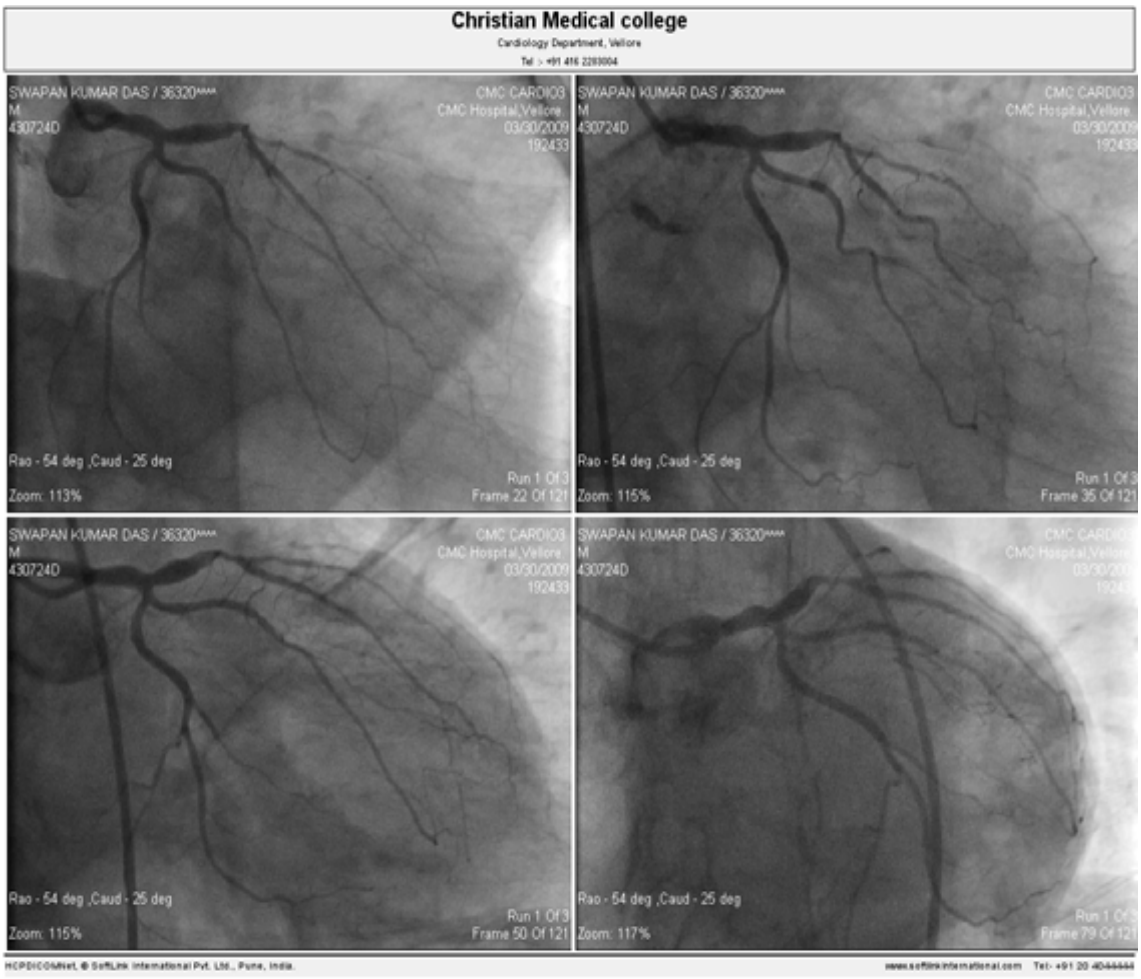


Figure 9. Rotational angiogram images of LCA injection. Images are seen from RAO caudal to LAO caudal showing a proximally occluded LAD. The distal LAD is seen filling from left to left collaterals.

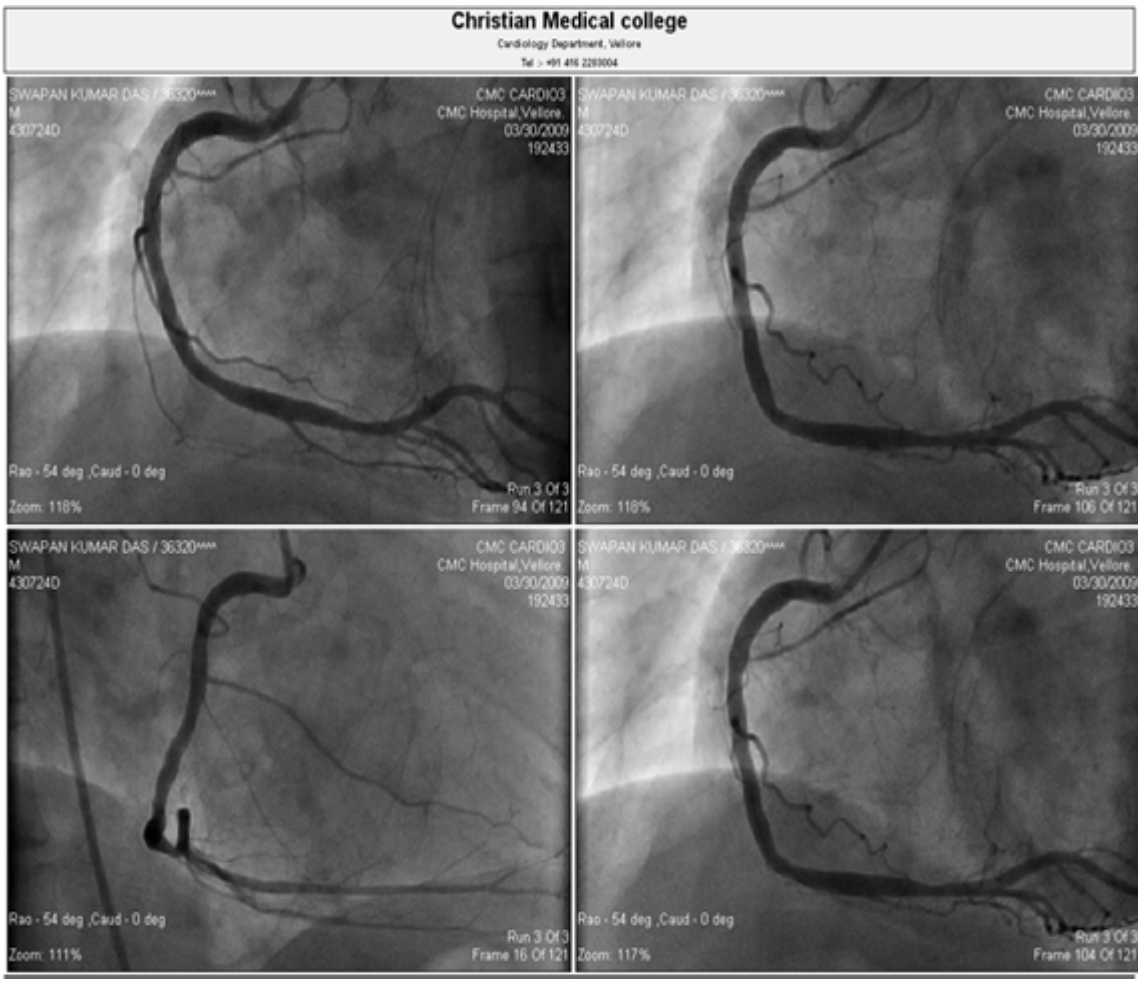


Figure 10. Rotational angiogram images of RCA injection. Images are seen from RAO caudal to LAO caudal showing a normal dominant RCA.

Image quality was good in all cases. Additional views were taken in 15 patients with significant coronary artery disease but these did not provide any additional information for assessment of lesion severity (% stenosis) and further management. Of the 64 angiographies done, 43.8% had normal coronaries. 12.5%, 14.1%, 10.9%, 12.5%, 1.6% and 4.7% had minor, single, double, triple, left main with double and left main with triple vessel disease respectively. Of

these patients 65.6% were advised medical management. 18.8% and 15.6% were advised coronary angioplasty and coronary bypass graft surgery respectively.

No patients had any adverse effects and there was no mortality.

DISCUSSION

In the present study, we have tested the feasibility of performing rotational angiography in routine practice, in a busy cardiac catheterization laboratory setting. Though it is a relatively new technique, it could be learnt and applied effectively in terms of being able to perform it routinely on a day to day basis.

The mean total contrast volume used for rotational coronary angiography in this study was 22.44 ± 5.16 ml. This was significantly less than that used for standard coronary angiography, according to data obtained from unpublished data in Christian Medical College, Vellore which was 38.16 ± 7.7 ml. Our findings confirm prior reports that rotational coronary angiography reduces patient exposure to contrast medium. The magnitude of reduction in contrast exposure by 41.19% in our study was similar to the reduction reported by Akhtar et al in 2005, who had used a Flat-Panel detector similar to that used in our study (40%) [30].

Maddux et al. in 2004 had reported a 33% reduction in contrast volume using an older imaging system for rotational angiography[28]. Kuon et al. previously noted a 61% reduction in contrast exposure by rotational angiography. However, this finding may be an overestimate given their older imaging technology and small sample size (n = 15) [27].

The radiation dose during rotational angiography in our study was 20.64 ± 7.18 $Gycm^2$. This was much lower (41 - 47%) as compared to prior studies. Maddux et

al. reported a mean radiation dose of 39 ± 19 $Gycm^2$ for rotational coronary angiography with the image intensifier Philips system[28]. Akhtar et al reported that the average radiation dose was 35 ± 14 $Gycm^2$ for rotational coronary angiography with the Philips Allura Xper FD 10 flat-panel detector[30]. The radiation dose for rotational angiography in this study was also found to be significantly less as compared with data for standard angiography which was obtained from previously published data from Christian Medical College, Vellore[67]. The radiation dose for standard angiography in this study was 55.86 ± 5.75 $Gycm^2$. This reduction in radiation dose with rotational angiography was comparable to other studies[28, 30].

There was a positive correlation between DAP and fluoroscopy time. However, DAP had a stronger correlation with BMI than fluoroscopy time. The relationship between patient weight and radiation dose has been established previously in invasive cardiologic studies. Ector et al. in 2007 found a significant correlation between patient radiation dose and BMI comparable to that found in our study[68]. Their study evaluated the impact of obesity on patient radiation dose during atrial fibrillation (AF) ablation procedures under fluoroscopic guidance. They concluded that there was a stronger correlation of DAP with BMI than with fluoroscopy time. However, this may be clinically more relevant in case of long procedures rather than short procedures like coronary angiography.

There is a definite learning curve involved in rotational angiography as was demonstrated by a significant decrease in fluoroscopy times with case numbers. This has been described in earlier studies on rotational coronary angiography by

Raman et al in 2004[69] and Akhtar et al in 2005[30]. The fluoroscopy times in these studies were timed from selective catheter engagement in each coronary ostium. However, in our study, fluoroscopy time was timed from the time of femoral arterial sheath insertion to the end on the angiography. Hence the fluoroscopy times are not comparable with earlier studies.

A sub group analysis was done on patients with compromised renal function and poor LVEF prior to the procedure. None of these patients had worsening of GFR post angiography. No patients in the study developed contrast induced nephropathy. This is probably due to the low contrast volume (22.44 ± 5.16 ml) used for rotational coronary angiography. Numerous studies have shown that the volume of contrast medium is a risk factor for contrast induced AKI. The mean contrast volume is higher in patients with contrast-induced AKI, and most multivariate analyses have shown that contrast volume is an independent predictor of contrast-induced AKI[48, 52, 56, 60].

However, 9 (14 %) patients had a GFR < 60 ml/min/1.73m^2 post-angiogram.

Five (55.6%) of these patients were diabetics. None of these patients had a rise in serum creatinine > 0.5mg/dl or > 25% of baseline serum creatinine at 48 hours after angiography. So, by definition, none of them had contrast induced nephropathy. However there was a significant difference between pre-angiogram and post-angiogram GFR. The mean pre-procedure GFR in these patients was 60.51 ± 7.22 ml/min/1.73m^2 and baseline serum creatinine was < 1.3 mg/dl. Hence these patients were not given saline hydration or NAC according to protocol. This could explain the worsening of GFR in these patients with a

'borderline GFR' most of who were diabetics at high risk for developing contrast induced nephropathy. Hence, it is likely that many such patients may be developing transient asymptomatic worsening of GFR which may go undetected since monitoring of serum creatinine is not a routine practice after coronary angiography in patients with normal serum creatinine prior to angiography. There are no studies so far which have evaluated the long term impact of this on renal function. Therefore estimation of GFR prior to use of radiocontrast may be a better way to assess actual renal function and risk for contrast induced nephropathy rather than serum creatinine which may be normal and hence misleading in many cases.

Even small volumes (~ 30 ml) of contrast medium can have adverse effects on renal function in patients at particularly high risk[61]. This could also explain the worsening of GFR in patients with a pre-procedural borderline GFR in our study. As a general rule, the volume of contrast received should not exceed twice the baseline level of eGFR in milliliters[62].

Though no definite parameters to assess image adequacy[70] were used in this study, assessment of coronary angiograms was done in terms of image quality and adequacy of anatomic information obtained, by the primary operator and a consultant cardiologist. Image quality was good in all cases. Additional views were taken in 15 patients with significant coronary artery disease but these did not provide any additional information for assessment of lesion severity (% stenosis) and further management. The information obtained by rotational coronary angiography was sufficient to plan management in all cases.

Thus rotational coronary angiography is a new technique which offers a significant reduction in contrast volume and radiation dose. Though easy to perform, there is a definite learning curve involved. Rotational angiography provides image quality which is comparable to standard angiography and in some cases even better, by means of providing a panoramic view of the entire coronary tree which is independent of the operator's ability to find the best view to visualize a part of a particular coronary artery. It appears to have a definite role in patients at risk for developing contrast induced nephropathy, by significantly limiting contrast volume. Rotational coronary angiography may also be of use in low risk patients, pre-renal transplant recipients and pre-valve surgery patients where it significantly saves precious time in a busy cath lab by means of reducing fluoroscopy and procedure times. By means of decreased dependence on the operator to find the optimal view, coupled with low risk patients, this procedure can be safely done by cardiology trainees in this group of patients, leaving senior cardiologists to focus on more complex procedures.

LIMITATIONS

1. Damping of pressures was noted in many patients after catheter engagement of the RCA ostium. Positioning and isocentering usually takes atleast 30 seconds but required to be hastened due to damping. This theoretically exposes the patient to a risk of bradycardia or ventricular arrhythmias on injection of contrast. However, none of the patients experienced any such complications in this study and no procedure was aborted due to this.
2. Fifteen patients had damping of pressures after RCA catheter engagement and did not have reflux of contrast. Hence, additional views were required to demonstrate reflux, ostial spasm and relief of the same with nitroglycerin.
3. The time taken for the rotational arc is a minimum of 4 seconds excluding the time for positioning and isocentering, which in real practice may take 30 seconds to 1 minute, depending on the experience and expertise of the technical staff. Hence a stable catheter position is of paramount importance without which the whole process of engaging, positioning and isocentering would have to be repeated. This would mean an additional expense of time, radiation and contrast.
4. Incase of a deep catheter engagement especially with the RCA, a careful pull-back of the catheter during rotational angiography may not be possible as there is a risk of catheter disengagement and having to repeat

the process afresh. Pull-back of the catheter to visualize ostial lesions also carries the same risk.

5. Though rotational angiography is feasible in obese patients and in patients with cardiomegaly as demonstrated in this study, it does require much more careful positioning and isocentering since panning the table as is possible with standard angiography is not an option. For the same reason, rotational angiography may pose difficulties in patients with abnormal positions of the heart.
6. Visualization of collaterals usually requires prolonged injection of contrast. Since the rotational arc lasts only 4 seconds, there were few patients with chronic occlusions in whom collaterals could not be clearly visualized. Also, the collaterals arising from contralateral vessels may not be captured in the field of the angiogram. This means that these patients would require additional views to visualize collaterals.
7. This procedure involves a learning curve for both the operator and assistants especially with regard to the isocentering and injection technique. Improper isocentering would cause segments of a vessel not being visualized. Failure to start injection just prior to cineangiography would cause the rotational arc to start before opacification of the coronary arteries and hence non-visualization of the coronaries for the initial few frames. Too rapid hand injection would cause depletion of contrast before the rotational arc is completed and the latter frames would not be opacified.

SUMMARY OF MAIN FINDINGS

1. Rotational coronary angiography is a practically feasible and easy technique which can be routinely performed in a busy cardiac catheterization laboratory setting.
2. The mean total contrast volume used for rotational coronary angiography in this study was 22.44 ± 5.16 ml (n = 64). This was significantly less ($p < 0.05$) as compared with the mean total contrast volume used for standard coronary angiography obtained from unpublished data in Christian Medical College, Vellore which was 38.16 ± 7.7 ml (n = 25).
3. The mean DAP in this study was 20.64 ± 7.18 $Gycm^2$. This was compared with data for standard angiography was obtained from previously published data from Christian Medical College, Vellore[67]. The radiation dose for standard angiography was 55.86 ± 5.75 $Gycm^2$. The difference was statistically significant ($p < 0.0001$). The 95 % CI of this estimate were 32.36 – 38.07.
4. There was a positive correlation of BMI and fluoroscopy time with DAP.
5. There was a reduction of fluoroscopy time with time and hence a definite learning curve was demonstrated.
6. In patients with LVEF < 50% and/or GFR < 60ml/min/1.73m^2, there was no significant worsening of GFR after rotational angiography. None of the patients developed contrast induced nephropathy.

7. Five patients with a baseline GFR > 60ml/min/1.73m^2 prior had a decline in GFR after angiography. However none of these patients had contrast induced nephropathy by definition. Hence, monitoring GFR before and after angiography may alert clinicians to early deterioration of renal function before an obvious rise in serum creatinine is noticed.
8. Rotational angiography provided good image quality and adequate anatomic information required to plan management, as was assessed by the primary operator and a consultant cardiologist.

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PROFORMA

Assessment of feasibility and utility of rotational coronary angiography in clinical practice

S.No:	Date:
Name:	Hospital No:
Age:	Sex:
Wt (kg):	Ht (kg):
BMI (kg/m^2):	TTD (cm):
BSA (m^2):	CTR (%):
LBW (kg):	

History of renal disease:	Yes / No
Prior renal surgery:	Yes / No
Diabetes Mellitus:	Yes / No
Hypertension:	Yes / No
Smoking:	Yes / No
Dyslipidaemia:	Yes / No
History of ACS:	Yes / No

Indication for coronary angiography:
Previous revascularization: PTCA / CABG

Baseline Measurements

Se Creatinine (mg/dl):
GFR (ml/min/1.73m^2)

- <30 -
- 30 -59 -
- ≥60 -

LV EF (%):

- <30 -
- 30 – 50 -
- >50 -

Hemodynamic status: Stable/Unstable

Contrast:

Total Contrast Volume (ml):
LCA:
RCA:

Addittional views:

Renals:
LV:

Fluoroscopy Time (min):

Cumulative DAP (mGycm^2):

Cumulative Air Kerma (mGy):

Post procedure measurements

Se Creatinine (mg/dl):
GFR (ml/min/1.73m^2):

- <30 -
- 30 -59 -
- ≥60 -

Hemodynamic status: Stable/Unstable

Quality of Images: Good/ Not good

Adequacy of images: Adequate/ Not adequate

Coronary Diagnosis: Normal/ Minor/ S/ D/ T/ LD/ LT

Renal Diagnosis: Normal/ Minor/ RAS

Adverse Effects:

1.
2.
3.

Mortality: Yes/ No

Plan for management: M/ P/ C

Glossary for Master Chart

Hosp no	- Hospital number
Ht	- Height
Wt	- Weight
BMI	- Body Mass Index
LBW	- Lean Body Weight
BSA	- Body Surface Area
DM	- Diabetes Mellitus
HTN	- Hypertension
DLP	- Dyslipidemia
ACS	- Acute Coronary Syndrome
Indication	- Indication for angiography
Eval	- Evaluation for CAD
Pre op	- Pre Operative
Pre Tx	- Pre renal transplant
TTD	- Trans Thoracic Diameter
CTR	- Cardio Thoracic Ratio
GFR1	- Glomerular Filtration Rate (pre angio)
LVEF1	- Left ventricular ejection fraction
H Status1	- Hemodynamic status (pre angio)
S	- Stable
Contrast	- Contrast used
O	- Omnipaque

V	- Visipaque
LCA	- Left Coronary Artery
RCA	- Right Coronary Artery
addl view	- Additional view
P Time	- Procedure Time
F Time	- Fluoroscopy time
DAP	- Dose Area Product
GFR 2	- Glomerular Filtration Rate (post angio)
H Status 2	- Hemodynamic status (post angio)
S	- Stable
Adequacy	- Adequacy of anatomic information
C Diagnosis	- Coronary diagnosis
N	- Normal
M	- Minor
S	- Single Vessel Disease
D	- Double Vessel Disease
T	- Triple Vessel Disease
LD	- Left main triple vessel disease
LT	- Left main double vessel disease
R diagnosis	- Renal diagnosis
RAS	- Renal artery stenosis
Plan	- Management plan
M	- Medical

P	- PTCA
C	- CABG
Y	- Yes
N	- No

Sno	Date	Name	Hosp No	Age	Sex	Ht	Wt	BMI	LBW	BSA	renal disease
1	16.01.09	Gangadhar Sardar	390316D	55	M	155	68	28.3	50.2	1.67	N
2	17.01.09	Krishnand Jha	004960D	65	M	160	58	22.7	47	1.6	N
3	17.01.09	Sk Taiyeb Mondal	391412D	53	M	163	60	22.6	48.7	1.64	N
4	17.01.09	Magen Thapa	389798D	41	M	171	71	24.3	56	1.83	N
5	17.01.09	Solomon Gebremedhin	387361D	54	M	161	69	26.6	52.4	1.73	N
6	19.01.09	Dhiren Das	389255D	48	M	176	65	21	54	1.8	N
7	19.01.09	Jayram Viswakarma	391452D	54	M	158	64	25.6	49.4	1.65	N
8	19.01.09	Basundhara Biswakarma	389522D	54	F	144	54	26	37	1.44	N
9	19.01.09	Kavitha Gadia	386851D	41	F	155	64	26.4	43.1	1.62	N
10	19.01.09	Sunil Chowdhary	171941D	66	M	164	75	27.9	55.7	1.82	N
11	19.01.09	Sripathi Mondal	384306D	58	M	160	60	23.4	48	1.62	N
12	20.01.09	Dinakaran	061558B	46	M	161	69	26.6	52.4	1.73	N
13	23.01.09	Sadhana Mukherjee	365833D	62	F	155	55	22.9	40.2	1.53	N
14	23.01.09	Eyakat Mollick	392477D	47	M	165	50	18.4	43.3	1.53	N
15	23.01.09	Prabhunath Yadav	188877D	51	M	162	67	25.5	51.8	1.72	Y
16	23.01.09	Surendra Prasad Singh	198509C	63	M	156	54	22.2	44.1	1.52	N
17	24.01.09	Ameer	378176D	57	M	165	65	23.9	51.6	1.72	N
18	24.01.09	Siddheshwar Dutta	392638D	58	M	165	65	23.9	48	1.63	N
19	24.01.09	Ganesh Patra	392830D	60	M	165	65	23.9	51.6	1.72	N
20	24.01.09	Mohit Ranjan Biswas	390496D	62	M	165	65	23.9	51.6	1.72	N
21	24.01.09	Pushpa	005296A	52	F	155	65	27.1	43.5	1.64	N
22	27.01.09	Noor Mohammed	386211D	45	M	179	90	28.1	66.6	2.09	N
23	27.01.09	Sugunamma	184569A	59	F	172	68	23	49.6	1.8	N
24	27.01.09	Ramswaroop Prasad	040202C	66	M	170	69	23.9	54.8	1.8	N
25	28.01.09	Santoshi Prasad	394863D	67	M	150	54	24	42.8	1.48	N
26	28.01.09	Mohan Prasad Gupta	393622D	58	M	170	54	18.7	46.5	1.62	N
27	30.01.09	Akbar Sardar	393810D	59	M	167	45	16.1	40.2	1.48	N
28	30.01.09	Mohelal Verman	276945D	54	M	169	90	31.5	46.3	1.61	N
29	31.01.09	Kanniyan Solomon	390065D	60	M	165	65	23.9	51.6	1.72	N
30	31.01.09	Mira Devi	915453B	48	F	162	73	27.8	54.3	1.78	N
31	02.02.09	Mallika	556788C	56	F	153	60	25.6	41.4	1.57	N
32	09.02.09	Rajendera Prasad Singh	402095D	49	M	165	66	24.2	52.1	1.73	N
33	09.02.09	Murugesan	802859B	59	M	166	89	32.3	61.1	1.97	N
34	09.02.09	Lina Bibi	398313D	48	F	149	67	30.2	41.8	1.61	N
35	09.02.09	Biswanath Verma	401685D	62	M	165	66	24.2	52.1	1.73	N
36	16.02.09	Anjan Kumar Paul	407472D	61	M	170	60	20.8	50.1	1.69	N
37	16.02.09	Prodyut Kumar Dutta	405998D	58	M	165	54	19.8	45.7	1.59	N
38	16.02.09	Kiruba Mani	400048D	57	F	154	56	23.6	40.4	1.53	N
39	23.02.09	Sulochana	807614C	68	F	150	47	20.9	35.8	1.4	N
40	26.02.09	Biswanath Halder	399949D	65	M	160	50	19.5	42.5	1.5	N
41	26.02.09	Dilip Kumar Mondal	408514D	51	M	156	58	23.8	46.1	1.57	N
42	05.03.09	Chandrasekaran	924171C	48	M	170	68	33.5	54.3	1.79	Y
43	05.03.09	Munna Rai	416260D	62	M	170	74	25.6	57.1	1.85	N
44	05.03.09	Nand Kishore Singh	406271D	54	M	168	51	18.1	44.3	1.57	N
45	05.03.09	Sridharan	413017D	52	M	164	58	21.6	47.8	1.63	N
46	05.03.09	Sati Ranjan Das	415721D	68	M	166	47	17.1	53.3	1.76	N
47	09.03.09	Jahar Lal Saha	414442D	57	M	179	64	20	54	1.81	N
48	16.03.09	Ashim Krishna Sarkar	575448D	54	M	160	60	23.4	48	1.62	N
49	16.03.09	Sekar	178353D	58	M	160	84	32.8	57.1	1.87	N
50	16.03.09	Ashok Bouri	421303D	35	M	165	57	20.9	47.4	1.62	N

51	16.03.09	Kalawati Mishra	419667D	62	F	154	66	27.8	43.4	1.64	N
52	16.03.09	Vasu	418660D	52	M	163	65	24.5	51.2	1.7	N
53	16.03.09	Indrajit Kumar Bose	420070D	58	M	162	56	21.3	46.3	1.59	N
54	16.03.09	Anandan	862454A	38	M	179	64	20	54	1.81	N
55	16.03.09	Rajesh Prasad Singh	422331D	49	M	178	79	24.9	61.7	1.97	N
56	16.03.09	Radhakrishnan	365796A	62	M	166	54	19.6	45.8	1.59	N
57	16.03.09	Fatik Chanra Bauri	421301D	48	M	161	59	22.8	47.7	1.62	N
58	23.03.09	Ajit Roy Chowdhury	426909D	58	M	173	50	16.7	44.3	1.59	N
59	23.03.09	Anjali Sen	301267D	64	F	158	71	28.4	46.1	1.73	N
60	23.03.09	Poornam	423577D	48	F	154	57	24	40.7	1.54	N
61	30.03.09	Swapan Kumar Das	430724D	46	M	177	61	19.5	51.9	1.76	N
62	30.03.09	Bhawani Shankar	429652D	65	M	161	58	22.4	47.2	1.61	N
63	30.03.09	Basant Kumar Deo	430266D	49	M	163	70	26.2	53.2	1.75	N
64	30.03.09	Gopal Chandra Roy	430183D	62	M	165	40	14.7	36.5	1.4	N

renal surgery	DM	HTN	Smoking	DLP	ACS	Indiacation	previous	TTD	CTR	Creat 1	GFR 1
N	Y	N	Y	N	Y	Eval	N	25.6	46	0.9	93.12
N	Y	N	N	N	Y	Eval	N	26.6	48	0.8	103.12
N	Y	Y	Y	N	N	Eval	N	23.7	49	1.3	61.38
N	N	Y	N	Y	Y	Eval	N	27.6	48	1.2	70.98
N	N	Y	Y	N	Y	Eval	N	28.4	51	0.9	113.79
N	N	N	N	Y	N	Eval	N	27.5	51	0.9	95.72
N	N	N	N	N	Y	Eval	N	26.4	48	1	82.76
N	N	Y	N	N	N	Eval	N	22.9	55	1	62.13
N	N	N	N	N	N	Pre op	N	23	52	0.7	98.01
N	N	Y	Y	N	N	Eval	N	27.8	45	1	79.46
N	N	N	Y	N	N	Pre op	N	25.7	49	1.2	65.6
N	Y	Y	N	N	N	Eval	N	26.2	46	1.2	69.28
N	N	N	N	N	N	Pre op	N	22.9	48	1	59.71
N	N	N	Y	N	Y	Eval	N	23.8	55	0.8	110.13
N	Y	Y	N	N	N	Pre Tx	N	29.1	57	6.8	9.17
N	N	Y	Y	N	N	Pre op	N	28.2	55	0.9	90.58
N	Y	Y	N	Y	N	Eval	N	28.2	45	1.2	66.33
N	N	N	Y	Y	N	Eval	N	29	38	1.1	73.08
N	N	N	N	N	N	LVD	N	30.3	51	1.1	72.57
N	Y	Y	Y	N	N	Eval	N	27	40	1.2	65.21
N	Y	N	N	Y	N	Pre op	N	25.1	57	0.7	93.4
N	N	N	Y	N	N	Eval	N	32.4	49	1.2	69.59
N	Y	Y	N	Y	N	Eval	N	24.9	43	0.7	91.03
N	Y	Y	N	N	Y	Eval	N	28.4	47	1.1	71.18
N	N	Y	N	N	N	Eval	N	24.4	54	1	79.22
N	N	Y	N	N	N	Pre op	N	25.8	52	1	81.57
N	N	N	N	N	N	Pre op	N	27.9	67	1.1	72.82
N	N	N	N	N	N	Pre op	N	30.1	48	0.9	93.46
N	Y	Y	N	N	Y	Eval	N	26	52	0.9	91.49
N	Y	Y	N	N	N	Eval	N	26.4	58	1.4	57.49
N	N	Y	N	N	N	LVD	N	23.7	60	1	60.96
N	Y	Y	Y	N	N	Eval	N	27.4	44	1.4	57.25
N	Y	Y	N	N	Y	Eval	N	30.9	44	1.2	65.87
N	Y	Y	N	N	N	Eval	N	24	55	1	62.9
N	N	N	Y	N	Y	Eval	N	31	38	1.4	54.58
N	Y	Y	Y	N	N	Eval	N	27	41	1.3	59.65
N	N	N	N	N	N	Eval	N	30.2	38	1.2	66.09
N	Y	Y	N	Y	Y	Eval	N	26.6	51	1	60.74
N	Y	Y	N	N	Y	Eval	N	21	52	0.9	66.18
N	N	N	N	N	N	Pre op	N	26.5	69	1.2	64.58
N	N	Y	Y	N	N	Eval	N	28.5	49	0.9	94.55
N	Y	N	N	N	N	Pre Tx	N	30	50	5.4	12.11
N	N	N	N	Y	Y	Eval	N	25.5	58	1.2	65.21
N	N	N	N	N	N	Pre op	N	26	51	1	82.76
N	Y	N	Y	N	N	Eval	N	28.3	43	1.2	67.58
N	N	N	N	N	Y	Eval	N	26.2	53	1.1	70.75
N	Y	N	N	Y	N	LVD	N	28.4	55	0.9	94.18
N	N	Y	N	N	N	Eval	N	26.7	55	0.9	93.46
N	Y	Y	N	N	N	Eval	N	28.9	45	1.2	66.09
N	N	N	N	N	Y	Eval	N	27.3	40	0.9	102.06

N	Y	Y	N	Y	N	Eval	N	24.3	65	0.7	90.12
N	Y	Y	N	Y	N	Eval	N	26.7	56	1	83.4
N	N	N	N	N	Y	Eval	Y	29.3	56	1.4	55.32
N	N	N	Y	N	N	Pre op	N	30	53	1.1	79.63
N	N	Y	Y	N	N	Eval	N	30.3	43	0.9	95.33
N	N	N	N	N	N	Pre op	N	25.8	55	1.1	72.09
N	N	N	Y	N	N	Eval	N	27.9	51	0.9	95.72
N	N	Y	N	N	N	LVD	N	25.7	51	1	81.57
N	N	Y	N	N	N	Eval	N	23	58	1.3	43.83
N	N	N	N	N	N	Eval	N	25.6	50	0.8	81.37
N	Y	N	Y	N	Y	Eval	N	28	46	1.1	76.6
N	Y	Y	Y	N	Y	Eval	N	25.8	57	1.2	64.58
N	Y	Y	N	Y	Y	Eval	N	29.4	55	1.2	68.4
N	N	N	Y	N	N	LVD	N	24.1	56	1.1	72.09

LVEF1	H Status1	Contrast	LCA	RCA	addl view	Volume	renals	LV	Others	Total Vol	F Time
45	S	O	18	7	0	25	0	0	0	25	2.18
57	S	V	12	5	0	17	0	0	0	17	2.07
48	S	O	14	5	0	21	0	0	0	21	2
41	S	O	14	3	10	27	30	0	0	57	3.1
61	S	O	16	5	5	26	15	0	0	41	3.1
52	S	O	18	5	0	23	0	0	0	23	2.15
58	S	O	15	5	0	20	0	0	0	20	2.5
56	S	O	10	4	0	14	15	20	0	49	2.28
45	S	O	12	4	0	16	0	40	25	81	1.52
57	S	O	18	5	4	27	22	0	0	49	1.52
57	S	O	16	4	24	44	0	0	0	44	2.53
57	S	O	20	5	0	25	15	20	0	60	1.55
56	S	O	12	5	0	17	0	0	25	42	1.07
40	S	V	17	5	5	27	0	0	0	27	3.07
56	S	V	20	7	0	27	0	0	0	27	1.16
57	S	O	16	5	0	21	15	0	0	36	2.23
56	S	O	18	5	0	23	15	20	0	58	1.53
58	S	O	14	7	0	21	0	0	0	21	1.6
42	S	O	18	5	0	23	15	20	0	58	1.6
57	S	O	15	5	0	20	15	20	0	55	1.53
58	S	O	13	3	0	16	0	0	25	41	2.46
52	S	O	15	4	4	23	0	0	0	0	1.47
56	S	O	12	4	0	16	15	0	0	31	1.33
57	S	O	16	5	0	21	15	0	0	36	2.04
56	S	O	14	5	0	19	15	20	0	54	2.04
56	S	O	15	5	0	20	0	0	0	20	1.2
52	S	O	14	5	5	24	0	20	0	44	1.57
55	S	V	16	6	0	22	0	0	25	47	2.55
45	S	O	12	5	5	22	0	0	0	22	2.46
57	S	V	20	5	5	30	15	20	0	65	3.27
40	S	O	12	5	0	17	15	20	0	52	2.27
57	S	V	16	5	10	31	15	20	0	66	3.55
30	S	O	13	5	0	18	15	20	0	53	2.1
43	S	O	11	5	5	21	15	20	0	56	1.57
31	S	V	14	3	3	20	0	0	0	20	1.33
57	S	O	17	5	5	27	15	20	0	62	1.38
57	S	O	14	5	5	24	0	20	0	44	0.53
57	S	O	14	5	5	24	15	20	0	59	2.29
57	S	O	16	5	5	26	15	20	0	61	1.38
56	S	O	16	5	0	21	0	0	25	46	2.05
54	S	O	16	5	5	26	15	20	0	61	1.08
55	S	V	16	5	0	21	15	20	0	56	0.5
44	S	O	16	5	0	21	15	20	0	56	3
57	S	O	12	4	0	16	0	0	0	16	0.43
57	S	O	13	5	15	33	0	20	0	53	1.16
40	S	O	12	5	5	22	15	20	15	72	1.4
32	S	V	16	5	0	21	0	0	0	21	1.53
55	S	O	14	4	0	18	15	0	0	33	1.14
56	S	O	16	6	0	22	15	20	0	57	1.5
44	S	O	14	5	0	19	0	20	0	39	0.37

57	S	O	14	5	0	19	15	20	0	54	2.01
41	S	O	14	5	0	19	15	20	0	54	0.48
40	S	V	14	5	20	39	0	0	0	39	1.32
57	S	O	18	8	0	26	0	20	25	71	2.04
57	S	O	14	5	0	19	15	20	0	54	1.03
52	S	O	14	4	0	18	0	20	0	38	1.02
56	S	O	14	5	0	19	15	20	0	54	0.51
30	S	V	16	5	0	21	0	0	0	21	0.4
55	S	V	16	5	0	21	15	0	0	36	1.04
57	S	O	16	5	5	26	0	0	0	26	0.43
43	S	V	16	5	0	21	0	0	0	21	0.54
35	S	V	16	5	0	21	15	0	0	36	1.15
30	S	V	16	5	0	21	8	0	0	29	1.15
35	S	O	16	5	0	21	0	0	0	21	1.34

DAP	Air Kerma	Creat 2	GFR 2	H Status 2	Image qual	Adequacy	Adverse effects	Mortality
30.993	412.68	0.9	93.12	S	Good	Y	N	N
18.287	246.97	0.9	90.1	S	Good	Y	N	N
21.74	284.13	1.3	61.38	S	Good	Y	N	N
29.097	385.19	1.3	64.66	S	Good	Y	N	N
29.097	385.19	0.9	113.78	S	Good	Y	N	N
16.414	226.42	1	84.77	S	Good	Y	N	N
26.977	387.68	1.1	74.14	S	Good	Y	N	N
17.535	236.12	0.9	70.16	S	Good	Y	N	N
17.186	243.43	0.8	84.01	S	Good	Y	N	N
17.186	243.43	1.1	71.98	S	Good	Y	N	N
27.59	404.02	1.3	59.85	S	Good	Y	N	N
21.65	292.67	0.8	110.61	S	Good	Y	N	N
14.23	187.67	1	59.71	S	Good	Y	N	N
13.396	183.89	0.8	110.13	S	Good	Y	N	N
24.343	342.38	Not don	Not done	S	Good	Y	N	N
16.562	225.69	1	80.21	S	Good	Y	N	N
22.565	316.766	1.4	55.52	S	Good	Y	N	N
12.902	172.31	1	81.57	S	Good	Y	N	N
35.047	448.6	1.1	72.57	S	Good	Y	N	N
21.178	281.21	0.8	104.11	S	Good	Y	N	N
21.525	283.62	0.7	93.4	S	Good	Y	N	N
32.616	559.38	1.2	69.59	S	Good	Y	N	N
17.679	257	0.6	108.75	S	Good	Y	N	N
24.365	391	0.9	89.73	S	Good	Y	N	N
20.593	273	1	79.22	S	Good	Y	N	N
16.557	219.43	1.2	66.09	S	Good	Y	N	N
17.43	229.94	1	81.29	S	Good	Y	N	N
28.056	350.746	1	82.76	S	Good	Y	N	N
20.467	342.19	0.9	91.49	S	Good	Y	N	N
30.22	576	1.2	68.68	S	Good	Y	N	N
16.591	231.175	1.4	41.34	S	Good	Y	N	N
23.071	350.02	1.4	57.25	S	Good	Y	N	N
34.507	471	1.2	65.87	S	Good	Y	N	N
33.843	440.42	1.1	56.35	S	Good	Y	N	N
15.69	251.61	1	80.47	S	Good	Y	N	N
22.874	304.8	1.3	59.65	S	Good	Y	N	N
21.024	293.6	1.2	66.09	S	Good	Y	N	N
23.367	335.19	0.9	68.59	S	Good	Y	N	N
22.874	304.8	0.9	66.18	S	Good	Y	N	N
16.652	212.765	1.2	64.58	S	Good	Y	N	N
20.466	276.34	0.9	94.55	S	Good	Y	N	N
14.87	212.43	NA	NA	S	Good	Y	N	N
38.091	525.92	1.2	65.21	S	Good	Y	N	N
9.871	133.18	1.3	61.14	S	Good	Y	N	N
14.98	212.15	1	83.4	S	Good	Y	N	N
12.181	184.24	1	70.75	S	Good	Y	N	N
18.656	264.85	0.9	94.18	S	Good	Y	N	N
19.145	260.54	0.9	93.46	S	Good	Y	N	N
38.822	635.45	1	81.57	S	Good	Y	N	N
14.8	206.7	1	90.38	S	Good	Y	N	N

22.381	391.78	0.7	90.12	S	Good	Y	N	N
22.036	362.91	1	83.4	S	Good	Y	N	N
24.843	338.34	1.2	66.09	S	Good	Y	N	N
16.54	230.01	1.1	79.63	S	Good	Y	N	N
22.909	314.05	0.9	95.33	S	Good	Y	N	N
14.676	209.81	1	80.47	S	Good	Y	N	N
15.685	223	0.9	95.72	S	Good	Y	N	N
12.139	169.82	1	81.57	S	Good	Y	N	N
21.518	317.2	1.3	43.83	S	Good	Y	N	N
8.406	114.36	0.9	71.03	S	Good	Y	N	N
15.103	206.192	1.3	63.17	S	Good	Y	N	N
13.912	180.95	1.2	64.58	S	Good	Y	N	N
7.276	396.901	1.4	57.25	S	Good	Y	N	N
7.782	106.569	1.1	72.09	S	Good	Y	N	N

C Diagnosis	R diagnosis	Plan
M	Not done	M
M	Not done	M
D	Not done	P
D	Minor	P
S	Normal	P
N	Not done	M
S	Not done	P
M	Normal	M
N	Not done	M
LT	Normal	C
S	Not done	C
T	RAS	C
N	Not done	M
S	Not done	P
M	Not done	M
N	Normal	M
M	Normal	M
N	Not done	M
N	Not done	M
N	Normal	M
N	Not done	M
N	Not done	M
N	Normal	M
T	Normal	C
N	Normal	M
N	Not done	M
N	Not done	M
M	Not done	M
T	Not done	C
S	Normal	P
N	Normal	M
LT	Normal	C
D	Normal	P
T	Minor	M
LD	Not done	P
D	Normal	P
N	Not done	M
N	Normal	M
T	RAS	C
N	Not done	M
M	Normal	M
N	Normal	M
S	Normal	P
N	Not done	M
D	Not done	P
D	Not done	P
D	Not done	C
N	Normal	M
T	Normal	C
S	Not done	M

N	Normal	M
T	Normal	M
T	Not done	M
N	Not done	M
N	Normal	M
N	Not done	M
N	Not done	M
M	Not done	M
N	Normal	M
N	Not done	M
S	Normal	M
LT	Normal	C
S	Normal	M
N	Not done	M